May 1999

Vol. 23 No. 5

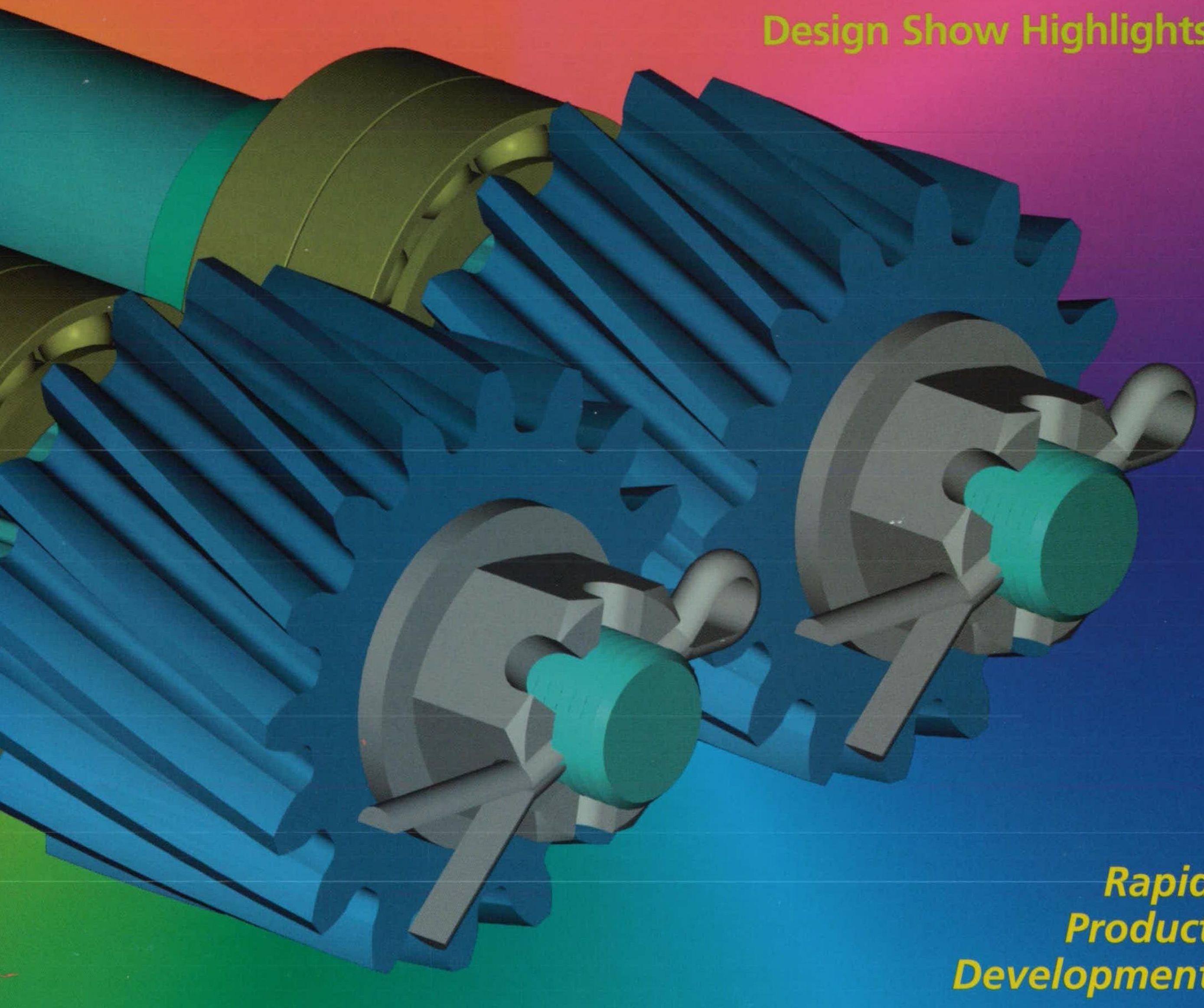
TECH BRIEFS

ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING

NASA's Invention of the Year

Product of the Year Winners

Design Show Highlights



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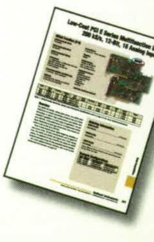

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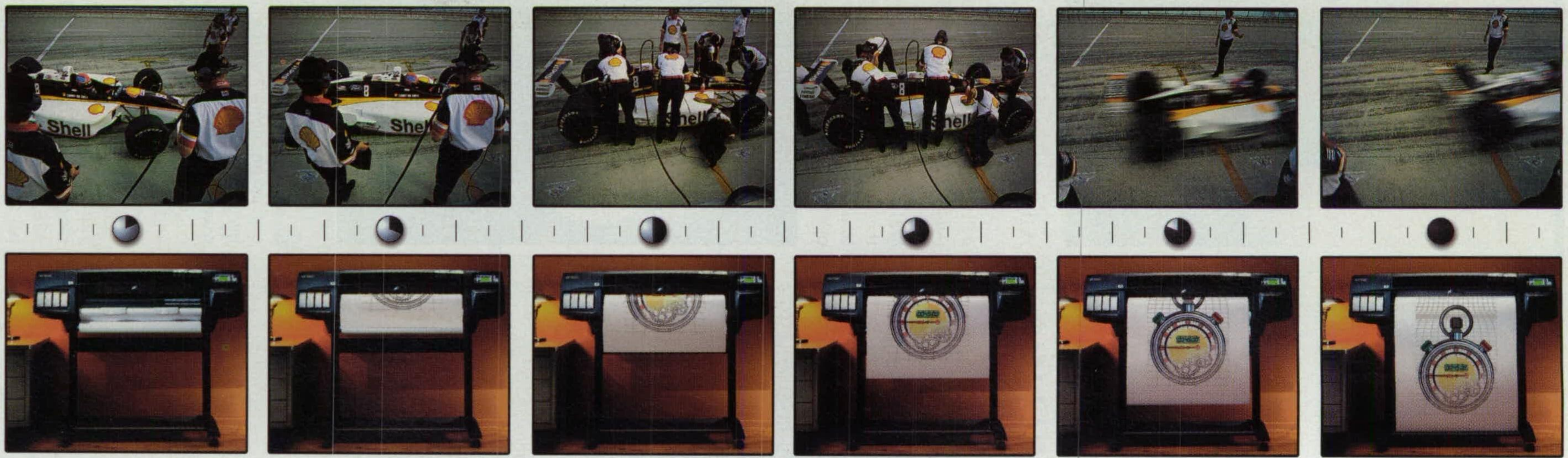

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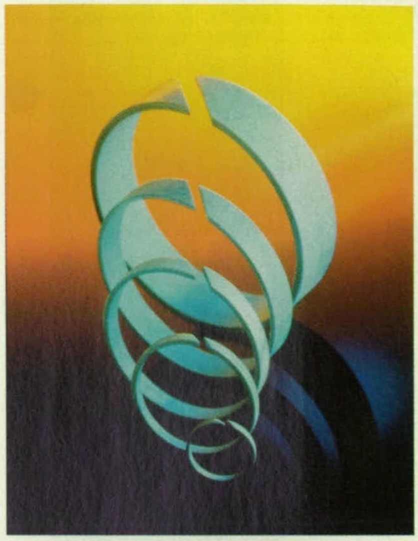

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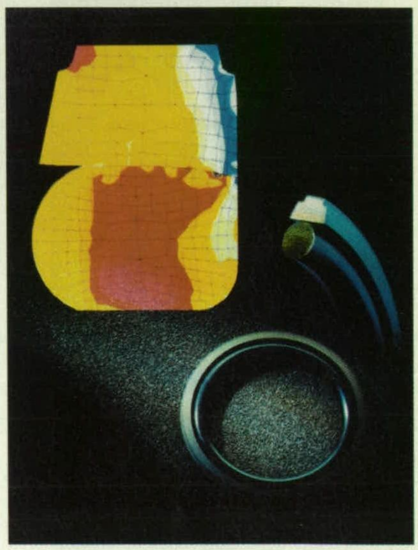

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TECH BRIEFS

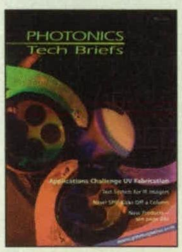
ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING

FEATURES

BRIEFS

DEPARTMENTS

SPECIAL SUPPLEMENTS



Contents *continued*

PRODUCT OF THE MONTH

ESDU engineering design database now available in electronic format from Information Handling Services.

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ON THE COVER

Dozens of new products were introduced recently at the National Design Engineering Show (NDES) in Chicago, including Mechanical Desktop® 4 mechanical CAD software from Autodesk, San Rafael, CA. The new release contains updated assembly-centric design features and commands. For instance, in this design automation example, the shaft generator, standard content, and screw connection commands help to streamline the process of creating 3D content, so designers do not have to draw each piece independently. For more information on this and other new products unveiled at NDES, see the feature beginning on page 22.

(Image courtesy of Autodesk)

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Technical/Managing Editor	**Ted Selinsky**
Sr. Technical Analyst	**Dr. Larry Grunberger**
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Administrator	**Daniel S. Goldin**
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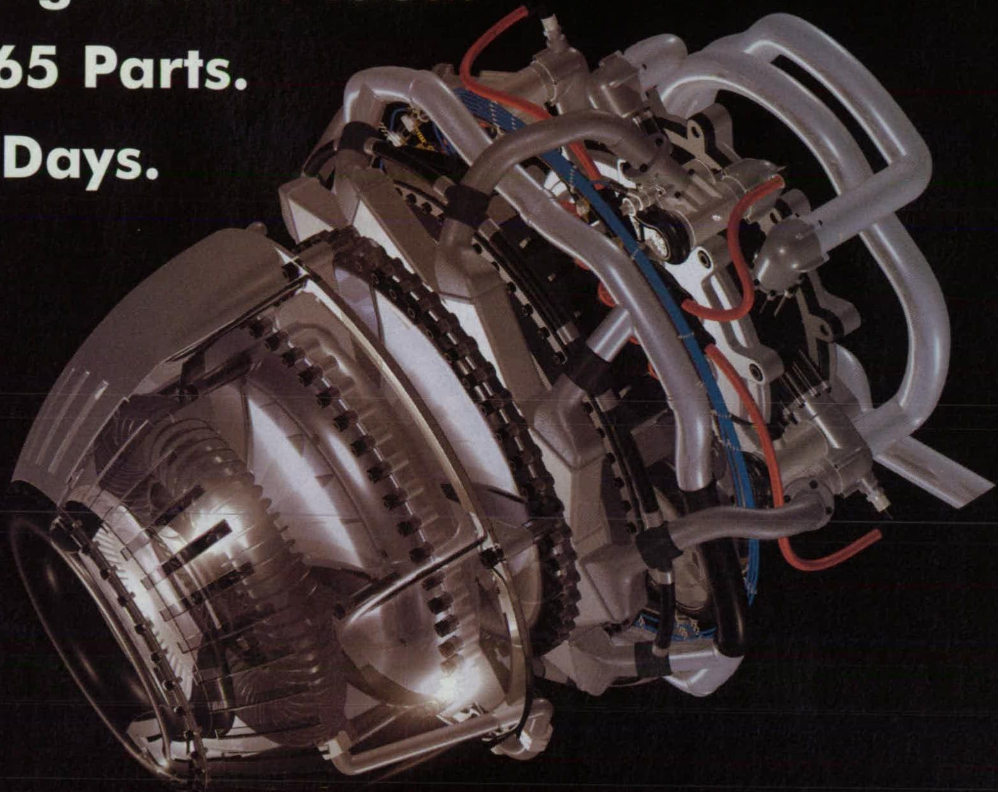

Revolutionary.

For a long time industrial designer Simon Floyd had an idea for a new type of engine. He also had at his fingertips one of the leading "high end" CAD systems, but the one thing he didn't have was spare time. "This is a complex assembly and the task of designing it in any conventional CAD system was just too daunting. However, once I got my hands on IronCAD, I finally had the power to realize my vision," says Mr. Floyd. IronCAD's unique Drag & Drop Solid Modeling and Design Flow™ Architecture gave him the power to not only work fast, but to innovate while he designed. He's become so enthusiastic about IronCAD, he now offers it to his clients. To see a case study of Simon Floyd's awesome engine design and to learn more about how IronCAD is powering the next industrial revolution, log on.

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NASA's Technology Sources

If you need further information about new technologies presented in *NASA Tech Briefs*, request the Technical Support Package (TSP) indicated at the end of the brief. If a TSP is not available, the Commercial Technology Office at the NASA field center that sponsored the research can provide you with additional information and, if applicable, refer you to the innovator(s). These centers are the source of all NASA-developed technology.

Ames Research Center
Selected technological strengths: Fluid Dynamics; Life Sciences; Earth and Atmospheric Sciences; Information, Communications, and Intelligent Systems; Human Factors.
Carolina Blake
(650) 604-0893
cblake@mail.arc.nasa.gov

Dryden Flight Research Center
Selected technological strengths: Aerodynamics; Aeronautics Flight Testing; Aeropropulsion; Flight Systems; Thermal Testing; Integrated Systems Test and Validation.
Lee Duke
(805) 258-3802
lee.duke@dfrc.nasa.gov

Goddard Space Flight Center
Selected technological strengths: Earth and Planetary Science Missions; LIDAR; Cryogenic Systems; Tracking; Telemetry; Command.
George Alcorn
(301) 286-5810
galcorn@gsfc.nasa.gov

Jet Propulsion Laboratory
Selected technological strengths: Near/Deep-Space Mission Engineering; Microspacecraft; Space Communications; Information Systems; Remote Sensing; Robotics.
Merle McKenzie
(818) 354-2577
merle.mckenzie@ccmail.jpl.nasa.gov

Johnson Space Center
Selected technological strengths: Artificial Intelligence and Human Computer Interface; Life Sciences; Human Space Flight Operations; Avionics; Sensors; Communications.
Hank Davis
(281) 483-0474
hdavis@gp101.jsc.nasa.gov

Kennedy Space Center
Selected technological strengths: Environmental Monitoring; Sensors; Corrosion Protection; Bio-Sciences; Process Modeling; Work Planning/Control; Meteorology.
Gale Allen
(407) 867-6626
galeallen-1@ksc.nasa.gov

Langley Research Center
Selected technological strengths: Aerodynamics; Flight Systems; Materials; Structures; Sensors; Measurements; Information Sciences.
Dr. Joseph S. Heyman
(804) 864-6006
j.s.heyman@larc.nasa.gov

John H. Glenn Research Center at Lewis Field
Selected technological strengths: Aeropropulsion; Communications; Energy Technology; High Temperature Materials Research.
Larry Viterna
(216) 433-3484
cto@grc.nasa.gov

Marshall Space Flight Center
Selected technological strengths: Materials; Manufacturing; Nondestructive Evaluation; Biotechnology; Space Propulsion; Controls and Dynamics; Structures; Microgravity Processing.
Sally Little
(256) 544-4266
sally.little@msfc.nasa.gov

Stennis Space Center
Selected technological strengths: Propulsion Systems; Test/Monitoring; Remote Sensing; Nonintrusive Instrumentation.
Kirk Sharp
(228) 688-1929
ksharp@ssc.nasa.gov

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Ken Dozier
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NASA ON-LINE: Go to NASA's Commercial Technology Network (CTN) on the World Wide Web at **http://nctn.hq.nasa.gov** to search NASA technology resources, find commercialization opportunities, and learn about NASA's national network of programs, organizations, and services dedicated to technology transfer and commercialization.

NASA Program Offices

At NASA Headquarters there are seven major program offices that develop and oversee technology projects of potential interest to industry. The street address for these strategic business units is: NASA Headquarters, 300 E St. SW, Washington, DC 20546.

Carl Ray
Small Business Innovation Research Program (SBIR) & Small Business Technology Transfer Program (STTR)
(202) 358-4652
cray@mail.hq.nasa.gov

Dr. Robert Norwood
Office of Aeronautics and Space Transportation Technology (Code R)
(202) 358-2320
rnorwood@mail.hq.nasa.gov

John Mulcahy
Office of Space Flight (Code MP)
(202) 358-1401
jmulcahy@mail.hq.nasa.gov

Gerald Johnson
Office of Aeronautics (Code R)
(202) 358-4711
g_johnson@aeromail.hq.nasa.gov

Bill Smith
Office of Space Sciences (Code S)
(202) 358-2473
wsmith@sm.ms.ossa.hq.nasa.gov

Roger Crouch
Office of Microgravity Science Applications (Code U)
(202) 358-0689
rcrouch@hq.nasa.gov

Granville Paules
Office of Mission to Planet Earth (Code Y)
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gpaules@mtpe.hq.nasa.gov

NASA's Business Facilitators

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Lewis Incubator for Technology
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Ames Technology Commercialization Center
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Marty Kaszubowski
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(757) 865-2140

If you are interested in information, applications, and services relating to satellite and aerial data for Earth resources, contact: Dr. Stan Morain, **Earth Analysis Center,** (505) 277-3622.

UpFront

PRODUCT OF THE MONTH

Engineering Sciences Data Unit (ESDU) International, a division of Information Handling Services, Englewood, CO, has released the ESDU database of mechanical, process, and structural engineering data items in electronic format, on the Internet and CD-ROM. The database contains more than 1,250 data items in 230 volumes. Each volume contains data items covering a specific engineering problem or component; data items may be methods, data examples, programs, or equations that are written to a common standard and are validated by committees of international engineering experts. The database is organized into subject areas such as aerospace, mechanical engineering, process engineering, and structural engineering. Topics covered include fluid mechanics, fatigue testing, noise and vibration, heat transfer, stress and strength, chemical engineering, and wind engineering. The data service is available on a subscription basis.

For More Information Circle No. 750

NASA Center Renamed for Glenn

NASA's Lewis Research Center in Cleveland, OH, has been officially renamed the John H. Glenn Research Center at Lewis Field. Ohio Senator Mike DeWine proposed the name change in recognition of Glenn's contributions to science and space, and to the state of Ohio. "I cannot think of a better way to pay tribute to two of Ohio's famous names, one an aeronautic researcher and the other an astronaut legend and lawmaker, than by naming a NASA research center after them," said NASA Administrator Daniel S. Goldin.

The center was built in 1941 and was re-named in 1958 for George William Lewis, research director for the National Advisory Committee for Aeronautics. "The blending of names reflects the pioneering research in aerospace technology that employees have performed throughout the center's history," said Center Director Donald J. Campbell.

For more information on the center, visit the web site at: http://www.grc.nasa.gov

NASA's Highway in the Sky

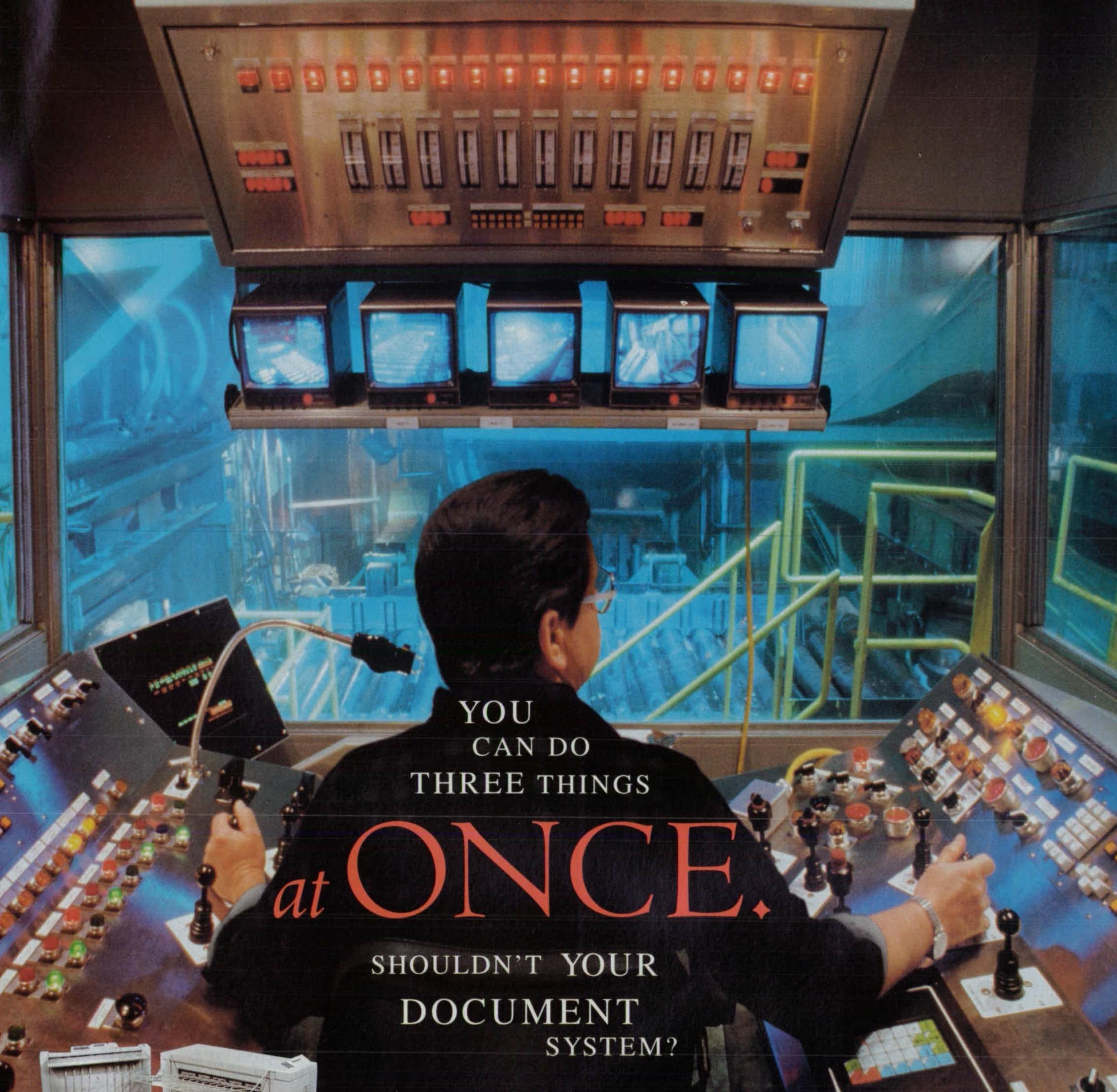
NASA's Advanced General Aviation Transport Experiments (AGATE) Alliance has awarded its Highway in the Sky (HITS) contract to a team led by Avidyne Corp. (Lexington, MA) and AvroTec (Portland, OR). The two companies and their partners will design the general aviation aircraft cockpit of the future, which is expected to be completed in 2001. The goal of HITS technology is to increase utility, safety, and ease of flying. Affordable glass cockpit technology will provide pilots with direct access to the information needed to safely determine routes, speeds, and proximity to adverse weather conditions and other aircraft.

Avidyne will design the HITS software using technology that will replace today's dials and gauges with large digital displays. AvroTec will develop computing and display hardware, building from their FlightMonitor line of multi-function displays. Partner companies include Raytheon Aircraft, Rockwell Collins, and AlliedSignal.

This image depicts the single-engine aircraft instrument panel showing computer-generated displays.

The AGATE Alliance aims to make single-engine/single-pilot planes as safe and economical as automobiles for trips ranging from 200 to 1,000 miles. Under the leadership and sponsorship of NASA and the Federal Aviation Administration (FAA), more than 70 companies have joined forces to establish new standards and validate emerging technologies in the U.S. small aircraft industry.

For more information, visit the AGATE Alliance web site at www.agate.larc.nasa.gov; Avidyne at www.avidyne.com; and AvroTec at www.avrotec.com



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Reader Forum

Reader Forum is devoted to the thoughts, concerns, questions, and comments of our readers. If you have a comment, a question regarding a specific technical problem, or an answer to a question that appeared in a recent issue, send your letter to the address below.

Your April Reader Forum included a letter from Joel Solomon requesting information on packaging that can be hermetically sealed and contain a nitrogen environment. I may know of a product that would meet Joel's requirements. The product is designed to contain viral and biochemical contaminants. Joel can contact me via e-mail for more information, and to let me know what size packages he is looking for.

Jan Nanning
nanning@bigfoot.com

I recently saw a science show on cable TV in which they showed a NASA scientist demonstrating the benefits of a silicon-based (99% air-1% silicon) material — a "solid smoke" that had excellent thermal benefits. I'm looking for more information on this material.

Bill Severa

*(**Editor's Note:** Bill, the "solid smoke" material, developed by NASA, is called Aerogel. It is made of silica, alumina, carbon, and other materials, and weighs less than the same volume of air. Aerogel is the lightest known solid and can protect virtually anything from heat or cold. A block the size of a human weighs less than a pound, but can support the weight of a compact car! For detailed information on aerogel, see NASA's Marshall Space Flight Center's Aerogel Web Page at: http://www.aerogels.com.)*

I am doing finite element analysis (FEA) models of thermocouple probes using mineral-insulated (MI) cable. I have a problem approximating the magnesium oxide insulation. I know the density, but I don't know the elastic modulus. Someone I spoke to gave me a value of 30 million psi for MgO insulation. This number seems high, and I am concerned that using this value adds too much stiffness to my model. Does anyone with experience modeling MI cable have any suggestions on how I might model this? Thank you.

Bob Griswold
griswoldb@harcolabs.com

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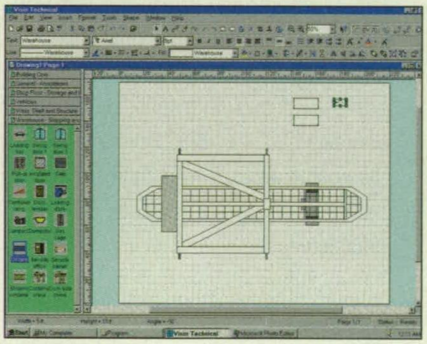
Drafting for the Non-Drafter

Visio Technical 5.0 Plus

Steven S. Ross

Visio has long been used by engineers and others who occasionally must draw, but who are not really drafters. It works by allowing users to drag pre-drawn "SmartShapes" into their drawings. There's an added bonus for those who worry about company-wide quality control: The shapes can be standardized so that a specific valve or circuit or chair always looks the same, and always carries the same data with it. This approach works best, of course, for drawing tasks that have lots of repetitive symbols involved — piping, circuits, layout of manufacturing processes, and so forth.

Visio has always come in two flavors. There's a simple version for typical management tasks such as drawing organizational charts or office layouts. And there's the more robust technical version for industrial design tasks. Both are essentially 2D drafting engines, but the technical version includes 4,000 SmartShapes for such tasks as HVAC control, electrical and electronic schematics, manufacturing and assembly drawings, site and landscape planning, and more.



Even site plans can be cobbled together in Visio. Here is a loading area with crane. The symbols (shapes) in the upper right corner represent containers. They don't scale automatically to the rescaled crane unless everything is connected. The best thing to do is to insert all the shapes and then rescale as necessary.

Technical 5.0 Plus, the latest version, includes support for AutoCAD Release 14 (and earlier) DWG and DXF files and for Bentley MicroStation DGN files. DXF is a reasonably standard ASCII-text file format that allows most CAD packages to exchange drawing files. The exchange is often far from perfect, but tends to work fairly well for basic mechanical design tasks.

Visio's support is not seamless; 5.0 Plus can read DGN, and read or write DXF and DWG. The DGN files are imported only as displayable backgrounds, onto which layers with Visio shapes and connectors can be added. MicroStation users can save files in DXF, which makes the resulting drawings completely editable in Visio.

You can import DWG files the same way (as displayable backgrounds), or you can allow Visio to convert one or more layers of the DWG file into Visio format for editing. If you choose the second option, entities in the DWG file are converted into Visio shapes, with preservation of any symbol attributes that may have been noted in the entities.

Visio promotional literature doesn't really talk about whether the full intelligence of a Visio SmartShape will survive a round trip to and from AutoCAD or MicroStation, or to Visio's own AutoCAD near-clone, IntelliCAD, which uses the DWG format. The answer is "no." To be fair, the problem is not an easy one to solve, and Autodesk has not solved it either for its shape-drag program, Actrix.

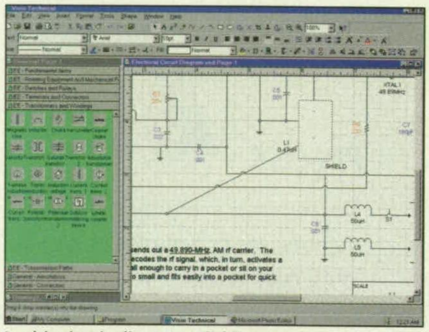
In cases where you convert, for example, a DWG file to Actrix or Visio, dimensions and 3D solids tend to disappear or to convert with minor, nagging problems.

We found Visio to translate DWG geometry a bit more cleanly than Actrix. Actrix seems to have a slight edge on translating entities (blocks) into intelligent shapes, however. Neither program displays referenced ("xref") drawings along with the DWG base drawing you translate.

Visio Technical 5.0 Plus also has new facilities management and process engineering tools. The neatest thing about the facilities management tools is a link to standard database software such as Paradox, Oracle, and Microsoft Access. The link makes it easier to handle space plans, and to track equipment company-wide.

The process engineering tools include piping and instrumentation diagrams (P&IDs) and process flow diagrams (PFDs). In a Visio drawing that uses these tools, even components that are connected to piping diagrams and schematics stay connected and automatically route themselves as you add new components.

Of course, not everything you draw can be handled with pre-drawn shapes and connectors. Visio Technical includes a basic set of drafting tools, and such niceties as a "valve builder" tool to make drawing of hydraulic or pneumatic valves rather simple.



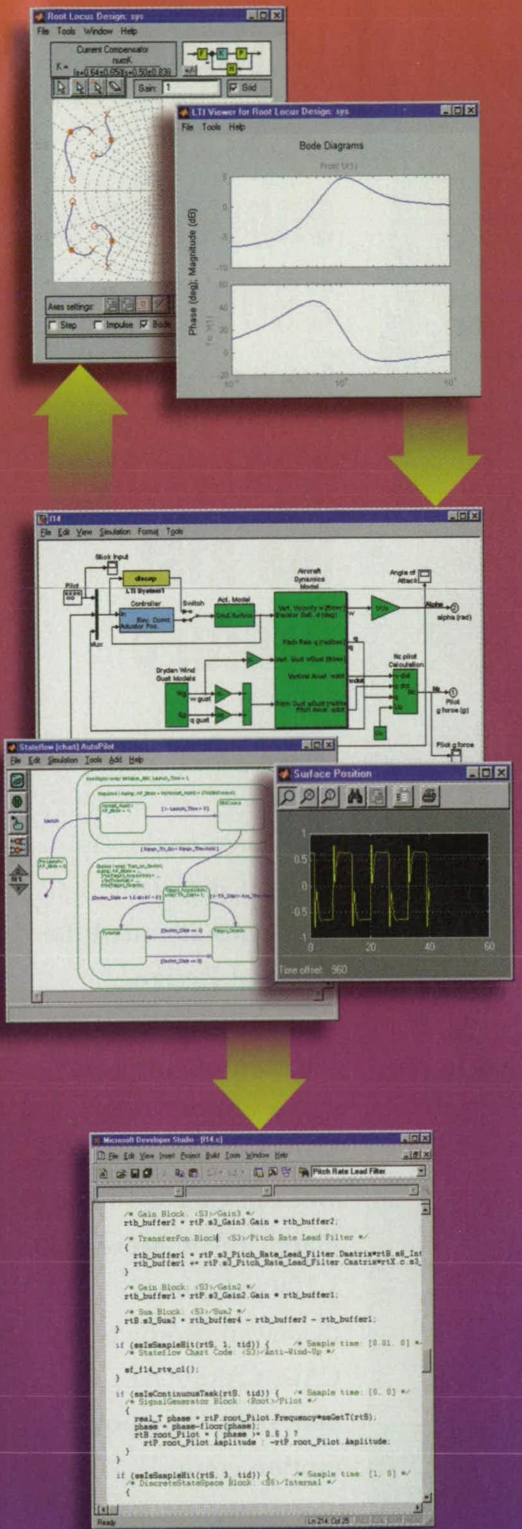
In this circuit diagram, clicking on the component shows its direct connection; the diagonal line extending to the lower left from the clicked object is "logical" only — Visio drew the line itself, based on the circuit logic.

On the electrical side, Visio automatically generates a SPICE (Simulation Program for Integrated Circuits Emphasis) input file or "netlist" of circuit designs you draw. These lists of components and their interconnections can be used by other design tools to validate or fine-tune your circuit.

This version carries an estimated street price of $349. It will run on a slow Pentium or even a 486 machine with 16 MB of RAM in Windows 95 (NT requires at least 24). For all but the simplest drawings, plan on using a Pentium 166 or faster and at least 32 MB of RAM. We found a Pentium 200 with 64 MB in Windows NT to be quite comfortable.

You can reach Visio at 520 Pike St., Ste. 1800, Seattle, WA 98101; 800-24-VISIO; www.visio.com/technical

Steven S. Ross is associate professor of journalism at Columbia University, New York, NY. He has authored three commercial software packages, including a units conversion program and an engineering calculations program.



Flight control system example

Our integrated control design solution allows you to move smoothly through the stages of your design process. Use MATLAB for data analysis and algorithm development (top), Simulink and Stateflow for both dynamic and event-driven simulation (middle), and Real-Time Workshop for generating prototype code (bottom).

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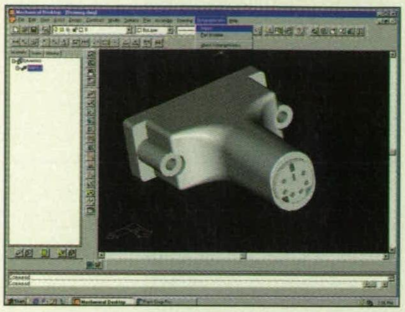
For More Information Circle No. 529

National Design Engineering Show: Leading National Design to the 21st Century

Design engineers from 21 different industries attended the National Design Engineering Show (NDES), one of four shows comprising National Manufacturing Week in Chicago from March 15-18. More than 1,100 exhibitors displayed products in CAD/CAM/CAE, materials, fluid power, motion control, electronics, rapid prototyping, and other areas. A number of exhibitors introduced new products at the show, including those on the following pages.

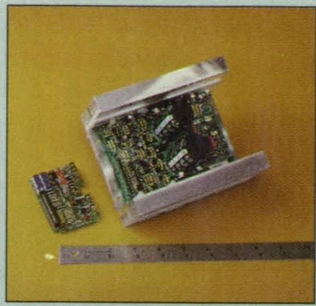
continued on page 24



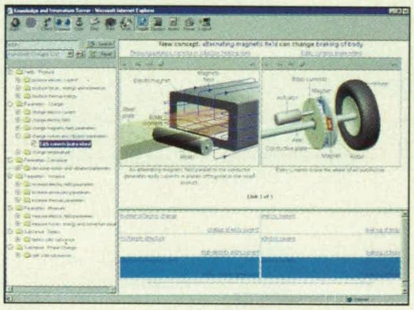
• SolidWorks Corp. (Concord, MA) announced XchangeWorks, a new data exchange plug-in that enables engineers to import solid modeling CAD data directly into AutoCAD and Mechanical Desktop®. It integrates seamlessly with existing AutoCAD and Mechanical Desktop mechanical design environments, allowing for direct translation of part files created with many CAD products such as SolidWorks®, Pro/ENGINEER®, and Unigraphics™. XchangeWorks is available on CD at no charge from the SolidWorks web site at: www.solidworks.com, or www.xchangeworks.com, or by calling 1-800-393-4118.

Products

• Hewlett Packard invited NDES attendees to visit the new Design Chain Engineering web site, where users will find solutions, case studies, events, and other information necessary to connect a firm's product development team for collaborative engineering with remote sites and suppliers. The site is designed to help companies gain time, money, and competitive advantages as they trim delays, diminish errors, reduce development costs, and speed total supply chain time to market. For more information, visit the HP Design Chain Engineering Website at www.hp.com/go/design_chain. *(Look for a report on HP's interactive audioconference on collaborative engineering in the June issue of* NASA Tech Briefs.*)*

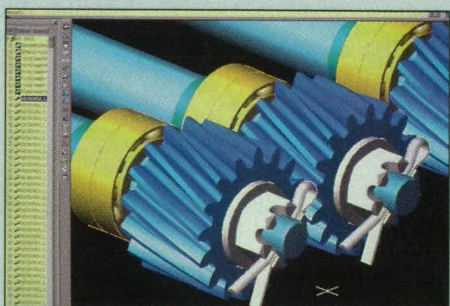


• Anacon Systems (Springfield, MO) introduced the Digi-Drive SO160090-100A and the SO170090-050A, two new motor controllers for half-horsepower single-phase induction motors. Using RISC-based proprietary control technology and software algorithms optimized for motor control functions, the series provides a wide range of speed adjustment. The customizable electronics easily integrate into existing or new single-phase motor applications such as fan, appliance, pump, and compressor control, and permit either analog or digital speed control through their A-to-D converter or serial interface input. Previously, multiple discrete speeds in single-phase motors were only available by using complex and expensive motor design or external relays and electronics to reach the two- or three-speed capability. The Anacon drives enable an electronic control system to allow motor speed to be set by the designer. For more information, contact Anacon at 512-762-4445; www.anaconsystems.com



• Knowledge and Innovation Server™ from Invention Machine Corp. (Boston, MA) is an intranet-based software tool that enables users to access, capture, and manage technical knowledge. Organizations can access a large knowledge base of 3D animated scientific effects and technical examples, add and share in-house technical knowledge, perform competitive patent analyses, and chart technical trends. Available via a corporate intranet, it is operated through a standard web browser. For more information, contact Invention Machine at 617-305-9250; www.invention-machine.com

• Visionary Design Systems (Santa Clara, CA) announced that future versions of its IronCAD design software will incorporate the solid modeling technologies from both Spatial Technology (ACIS®) and Unigraphics Solutions (Parasolid™) simultaneously. Until now, CAD systems could only operate on one underlying modeling kernel at a time. IronCAD will offer the addition of Parasolid to ACIS to enhance operability. Users will be able to intermingle parts based on the two different kernels, and will enable creation of parts based on either kernel. For more information, contact Visionary Design Systems at 408-969-8000; www.vds.com or www.ironcad.com



• Mechanical Desktop® 4 was previewed by Autodesk (San Rafael, CA). The latest version of the mechanical CAD software, and its add-on Mechanical Desktop 4 Power Pack, is built on top of AutoCAD® 2000, the newest version of the PC design software. Mechanical Desktop 4 will offer new assembly-centric design features, and design and drawing automation capabilities from Genius™ Desktop 3 software. The new version will be released this summer for Windows 95/98/NT platforms. For more information, contact Autodesk at 415-507-5000; www.autodesk.com

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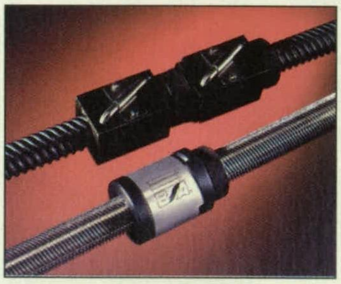
• Designing the wiring and cable harnesses for electrical and electronic systems is an old story. Most engineers are forced to wait for a physical prototype, which they then use to reverse-engineer the design of the system wiring. Then they sketch it out for manufacturing. Linius Technologies (Westborough, MA) offers Embassy 2.0, a MicroSoft Windows-based suite of 3D wire harness design tools that automates the complete design process, including design handoff to manufacturing. It accepts connectivity data from schematic capture packages and combines that with a 3D solid model of the assembly, enabling engineers to design wire harnesses and cables within the context of the 3D model. The new release includes more than 30 design enhancements. For more information, contact Linius at 508-616-9300; www.linius.com

• IBM and Dassault Systemes exhibited two recently introduced products: Version 5 Release 1 of CATIA, their CAD/CAM/CAE software, and Version 2 Release 2 of CATweb™, which offers high-speed web-based e-business navigation tools to explore native engineering data over the web. The new version of CATIA for Windows NT and UNIX is built using STEP, Java, CORBA, and OLE standards. A built-in knowledge engine guides users through a task by combining explicit rules of product behavior with interactive capture of design intent. CATweb allows downloading of multiple 3D models and 2D drawings on the client's machine. It also provides capabilities for design review with new annotation and mark-up features. For more information on CATIA, visit Dassault at www.dsweb.com; for information on CATweb, visit IBM at www.ibm.com



• Ball Screws and Actuators (San Jose, CA) announced the rollout of its 1" XC Series plastic antibacklash nut assembly. The one-inch size barrier has been out of reach for antibacklash plastic nuts because load requirements in much light and medium manufacturing can be as much as 500 pounds. BSA says its new nut assembly uses an advanced plastic compound that offers zero backlash for its lifetime at half the cost of a ball screw. It also incorporates BSA's patented ActiveCAM technology, which uses a stainless steel cam that automatically rotates and produces high axial rigidity without sacrificing life, torque, or positional accuracy, according to BSA. For more information, contact BSA at 408-629-1132; www.ballscrews.com

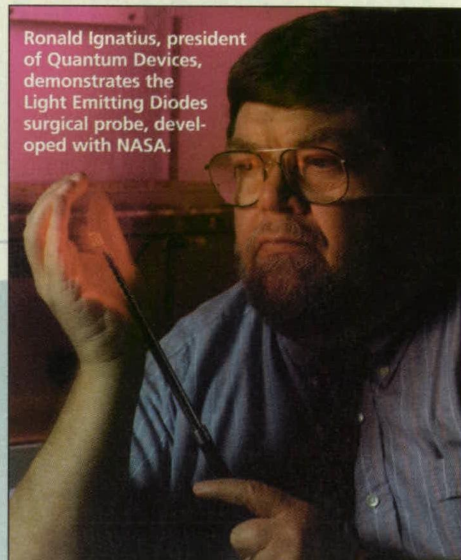
Space for Business

In the NDES Motion Hall, NASA showcased its newest technologies and presented attendees with the opportunity to view first-hand the future of space exploration and its applicability to industry. Exhibits in the NASA pavilion illustrated how NASA works with businesses to develop the products and technologies of tomorrow, and how to turn those technologies into products that benefit Americans. "Many new technologies coming out of these programs will find their way into industrial and consumer products," said Vernotto McMillan, deputy director of NASA's Marshall Space Flight Center's Technology Transfer Office.

Representatives from the NASA Space Product Development Program were on hand to talk with companies interested in learning more about the benefits of doing commercial work through the program. Other sections of the NASA exhibit included microgravity product demonstrations, industrial solutions processes, technology transfer collaborations, and a mock-up of a portion of the International Space Station.

One technology on display was special lighting that had been developed for NASA's commercial plant growth experiments in space, but is now being used to treat cancer. The Light Emitting Diodes surgical probe consists of 144 pinhead-sized diodes, is 9" long, and is about 1/2" in diameter. NASA's industry partner, Quantum Devices of Barneveld, WI, improved the LEDs and is working on new applications for them. The probe was developed for photodynamic cancer therapy under a NASA Small Business Innovation Research (SBIR) program grant managed by NASA's Marshall Space Flight Center, Huntsville, AL.

A keynote presentation was given by a panel of NASA engineers and commercial outreach officials. "NASA: Providing Solutions for the Manufacturing Industry" highlighted some of the hottest new technologies coming out of the space program that are available to U.S. companies, and described how to access them. These included embedded web technology and a segmented cold cathode display panel for flat-panel theatervision TV.



Ronald Ignatius, president of Quantum Devices, demonstrates the Light Emitting Diodes surgical probe, developed with NASA.

For more information, visit NASA Marshall's Technology Transfer Center web site at: www.nasasolutions.com; for information on the Space Product Development program, visit http://microgravity.nasa.gov

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The *NASA Tech Briefs* Readers' Choice Product of the Year Award winners (left to right): Peter McHugh accepts for Omron Electronics, the Bronze winner; Ryan McDonald for National Instruments, the Gold winner; and Bob Kadarauch for InPart, the Silver winner. (Photo by Michael Kardas)

The Product of the Year Finalist awards are displayed by representatives from (left to right) Waterloo Maple, Hyde Park Electronics, IOtech, Raytek, DuPont Performance Lubricants, Algor, and Haptic Technologies. (Photo by Michael Kardas)

NASA Tech Briefs Product of the Year Awards

For the second consecutive year, *NASA Tech Briefs* hosted a gala reception at the top of the John Hancock Center during NDES to present its 1998 Readers' Choice Product of the Year Awards. The fourth annual awards were voted on by the readers of *NASA Tech Briefs*, who turned out in record numbers to vote for the Gold, Silver, and Bronze award winners. Nine other Product of the Year Finalists were presented with awards; all had received Product of the Month honors during 1998.

Each month, *NASA Tech Briefs* editors choose a Product of the Month, which is the one product they feel exhibits exceptional technical merit and practical value. In the December issue, readers are invited to vote for the one product of those 12 highlighted during the year that represents the most innovative product introduced to the engineering community. The product receiving the most votes is the Gold Award winner, and Product of the Year.

This year's Readers' Choice Product of the Year Gold Winner was LabVIEW 5.0 graphical instrumentation software from National Instruments, Austin, TX. The award was presented to Ryan McDonald of National Instruments by *NASA Tech Briefs'* Chief Editor Linda Bell; Senior Editor Bob Clark; and Associate Editor Suzanne Bilyeu. LabVIEW 5.0 provides tools for system developers to create distributed applications, whereby various sections of code can execute on different machines across a network.

The Silver Product of the Year Award was presented to InPart of Saratoga, CA, for the DesignSuite® Internet-based library of 3D CAD models and detailed specs for mechanical components from leading U.S. suppliers. The models can be viewed and downloaded directly to the user's 3D CAD system.

Omron Electronics of Schaumburg, IL, took home the Bronze Award for its F30 machine vision system. The miniature system incorporates all of the elements of a machine vision system — the camera lens, lighting, and processor — into a 3 × 3 × 6" assembly that sets up in minutes.

The following companies were honored as Product of the Year Finalists:

- Algor, Inc. (Pittsburgh, PA) for Release 12 of its finite element analysis based mechanical engineering software;
- IOtech (Cleveland, OH) for the Personal Daq™ full-featured PC-based data acquisition systems utilizing the Universal Serial Bus (USB);
- Waterloo Maple (Waterloo, ON, Canada) for Release 5 of Maple V technical computing software;
- DuPont Krytox Performance Lubricants (Wilmington, DE) for Krytox® XP lubricants that include a soluble additive to enhance performance of PTFE greases and oils;
- Raytek (Santa Cruz, CA) for the Thermalert® GP two-piece infrared temperature monitoring system;
- Hyde Park Electronics (Dayton, OH) for the Superprox® Model SM607 small-target, ultrasonic proximity sensors;
- SPSS (Chicago, IL) for SigmaPlot 5.0 scientific graphing software for automated graphing and data analysis;
- Haptic Technologies (Montreal, Canada) for the PenCAT/Pro® 3D pen with force-feedback that allows CAD designers to feel objects on the computer screen; and
- Inova Computers (Osterville, MA) for the ICP-K233 family of 3U CompactPCI single-board computers.

All readers who submitted ballots in the Product of the Year contest were placed in a random drawing to win valuable software donated by winners of last year's Product of the Year awards. Congratulations to these *NASA Tech Briefs* readers:

- Paul M. Reilly of Fujitsu C.P.T., San Jose, CA: Winner of CADKEY 98 mechanical design software from Baystate Technologies, Marlborough, MA; and
- Martin Holland-Bak of Willamette Valley Co., Eugene, OR: Winner of MATLAB technical computing software from The MathWorks, Natick, MA.

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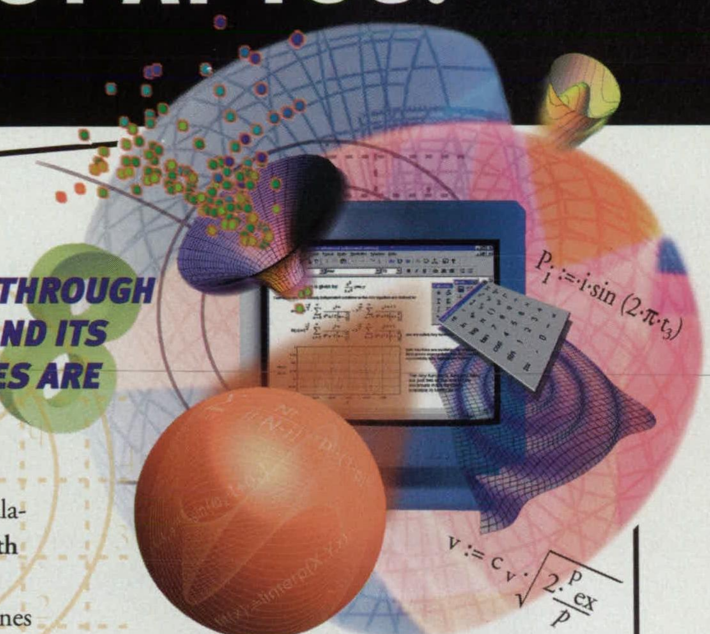

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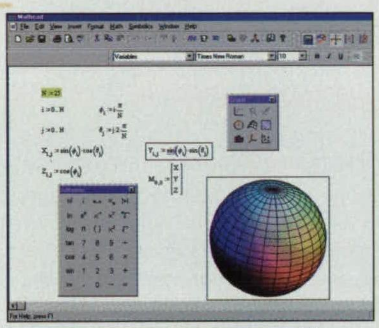

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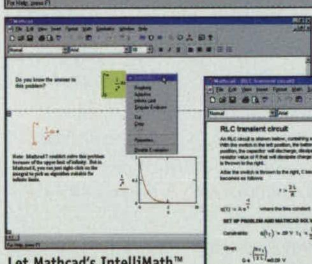

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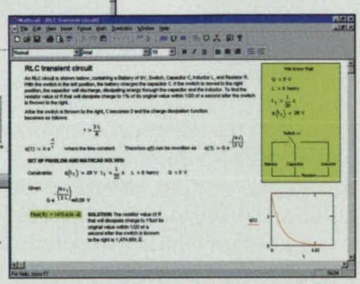

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Top Inventions of NASA 1998

NASA Selects Top Inventions of the Year

From an unusually strong field of candidates, NASA has selected a spacecraft stabilization device and a high-temperature resin material as the agency's top inventions for 1998. NASA's Commercial Invention of the Year award went to PETI-5, a material developed by three scientists at Langley Research Center. Charles E. Clagett of Goddard Space Flight Center was unanimously chosen as NASA's Government Inventor of the Year for designing the Apparatus for Providing Torque and for Storing Momentum Energy.

A Versatile Substance

PETI-5 — short for "Phenylethynyl Terminated Imide Oligomers," fifth composition — was NASA's unanimous choice for Commercial Invention of the Year. The substance can be used both as a glue that holds fibers together and as an adhesive with a variety of aerospace and commercial applications. It was developed at Langley Research Center, Hampton, VA, by Paul Hergenrother, Joseph Smith, and Brian Jensen.

PETI-5 originally was conceived for the High-Speed Research (HSR) Program, a joint effort between NASA and private industry. HSR required a composite matrix and adhesives that would be strong, lightweight, easy to process, resistant to aircraft fluids, and able to withstand temperatures of 350° F for up to 60,000 hours. No materials were available that met all of these requirements.

PETI-5, a single material, was developed in both composite and adhesive forms to satisfy the HRS specifications. Its chemical composition allows it to cure into a tough, heat-resistant plastic, which is easily formed into complex parts with application of heat and mild pressure. PETI-5 can be processed from readily available chemicals, is non-toxic, and adjusts to environmental changes.

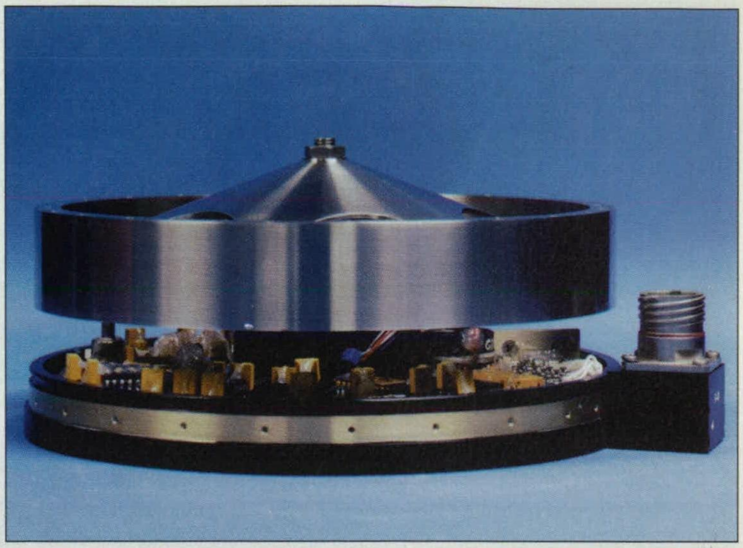
According to NASA, private industry already has shown considerable interest in PETI-5. The material has been licensed to Culver City Composites, a composite prepreg supplier; Imitec, Inc., a resin supplier; Fiberite, Inc., a prepreg supplier; and Cytec Engineered Products, Inc., an adhesive supplier.

Several PETI-5 products are now available commercially, including composite matrix prepregs, supported film adhesives, paste adhesives, core splice materials, and self-filleting film. These products have resulted in approximately $10 million in sales, with NASA receiving about $475,000 in royalties.

PETI-5 is also NASA's nominee for the National Inventor of the Year award, sponsored by the Intellectual Property Owners, Inc. (IPO), in cooperation with the U.S. Patent Office.

PETI-5, a versatile, high-temperature resin and adhesive, was used in the fabrication of this fuselage subcomponent. The material also cures into a tough, heat-resistant plastic that is easily formed into complex parts.

Re-Inventing the Reaction Wheel


The Apparatus for Providing Torque and for Storing Momentum Energy provides approximately twice the torque and 40 times better dynamic balance of comparable commercial wheels, at less than half the cost.

The Apparatus for Providing Torque and for Storing Momentum Energy was developed for NASA's Small Explorer (SMEX) program. For the latest SMEX spacecraft, NASA required a compact reaction/momentum wheel that could accelerate at a high rate with little noise and vibration. No commercially available reaction wheel had met the requirements.

Charles Clagett, who heads the Component and Hardware Systems Branch at Goddard Space Flight Center in Greenbelt, MD, delivered a durable, compact design that has at least a four-year life expectancy. The device, also known as the SMEX Reaction/Momentum Wheel, provides approximately twice the torque and 40 times better dynamic balance of comparably sized commercial reaction wheels at less than half the cost. This low-noise device also allows detection of signals that would have been obscured by previous reaction wheels. According to NASA, Clagett's invention has enabled Goddard Space Flight Center to carry out missions that could not be supported by previous technology. The SMEX Reaction/Momentum Wheel has been used successfully in the last two SMEX projects: the Transition Region and Coronal Explorer (TRACE) mission and the Submillimeter Wave Astronomy Satellite (SWAS).

Goddard has licensed the SMEX Reaction/Momentum wheel to CTA Space Systems and to Ithaco Inc., a manufacturer of flywheel-type reaction/momentum wheels. CTA Space Systems, a satellite manufacturer, has used the NASA invention on its GEM Star I and Early Bird 3 satellites. Orbital Sciences Corporation, which recently purchased CTA Space Systems, is using the SMEX wheel on its OrbView 3 satellite.

NASA's top inventors were honored during a ceremony at NASA Headquarters, where they received award checks and certificates. Here are the remaining 1998 Invention of the Year nominees:

- **Ames Research Center:** Low-Density Resin Impregnated Ceramic Article Having an Average Density of 0.15 to 0.40 G/CC; and Low-Density Resin Impregnated Ceramic Article and Method for Making the Same. Inventors: Huy K. Tran, William D. Henline, Ming-ta S. Hsu, Daniel J. Rasky, and Salvatore R. Riccitiello. NASA Case # ARC-12011-1.
- **Goddard Space Flight Center:** Micro Pulse Laser. Inventor: James D. Spinhirne. NASA Case # GSC-13493-1.
- **Johnson Space Center:** Rotary Blood Pump and Method for Reducing Pumping Damage to Blood. Inventors: Richard J. Bozeman, James W. Akkerman, Gregory S. Aber, George A. Van Damm, James W. Bacak, Paul A. Svejkovksy, and Robert J. Benkowski. Contributors: Michael E. DeBakey, Cetin Kiris, Dochan Kwak, and Bernard J. Rosenbaum. NASA Case # MSC-22424-1 and MSC-22822-1 (ARC-14087).
- **Kennedy Space Center:** Particle Fallout/Activity Sensor. Inventors: Curtis M. Ihleford, Robert C. Youngquist, John S. Moerk, and Kenneth A. Rose, III. Contributors: William Haskell, Robert Cox, Paul Morgan, Timothy Hodge, Christian Schwindt, and Steven Klinko. NASA Case # KSC-11687-1.
- **Langley Research Center:** Apparatus and Method for Measuring Strain in Bragg Gratings. Inventor: Mark E. Froggatt. NASA Case #LAR-15318-1.
- **John H. Glenn Research Center:** Process for Non-Contact Removal of Organic Coatings from the Surface of Paintings; Atmospheric Pressure Method and Apparatus for Removal of Organic Matter with Atomic and Ionic Oxygen. Inventors: Bruce A. Banks and Sharon K. Rutledge. NASA Case # LEW-1603-1 and LEW-20002-1.
- **Marshall Space Flight Center:** Selectively Lockable Knee Brace. Inventors: W. Neill Myers, Michael D. Shadoan, John C. Forbes, Kevin J. Baker, and Darron C. Rice. NASA Case # MFS-28991-1. Parachute Having Improved Vent Line Stacking. Inventor: John E. Hengel. NASA Case # MFS-28508-1.

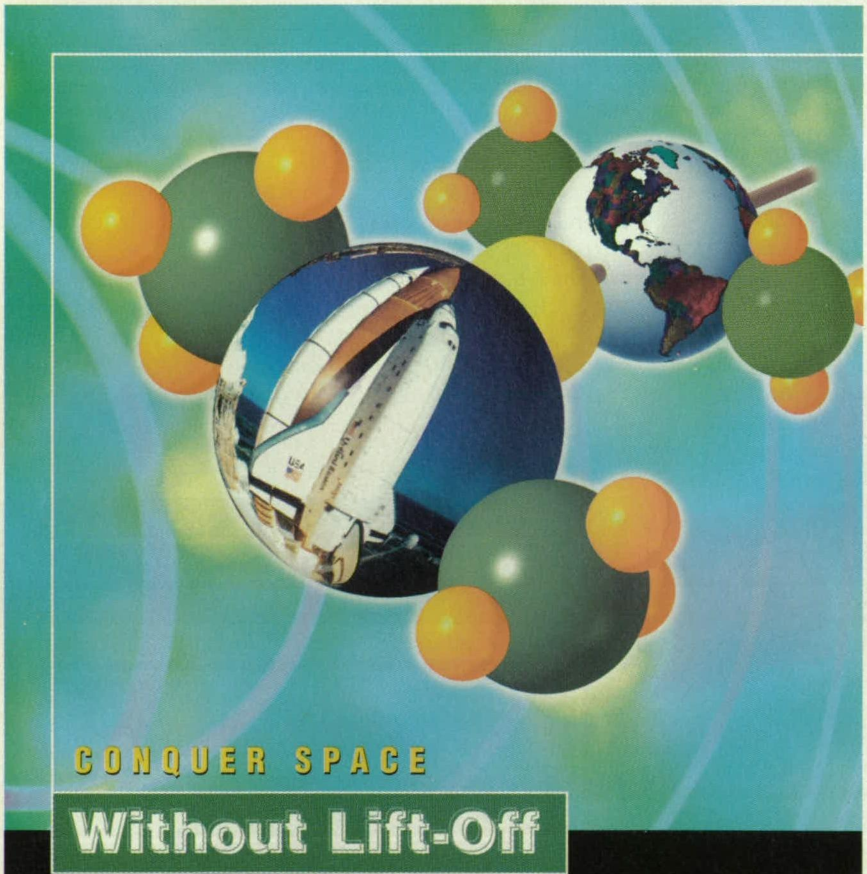
Commercialization Opportunities

GPS "Compound Eye" Attitude Sensor

A proposed GPS sensor would give information on approximate attitude as well as on position. This sensor would be based on a concept that is related to that of an insect's compound eye.
(See page 36.)

Acoustical-Sensor Assemblies for Use in Flows

Improved sensor assemblies measure acoustic signals in gases or liquids flowing in or around any of a variety of moving or stationary objects. These objects can be land vehicles, aircraft, submarines, and other structures exposed to winds or water streams.
(See page 44.)



Biotelemetry Using Implanted Unit To Monitor Preterm Labor

This system monitors key physiological parameters of a fetus and its uterine environment. The main purpose is to detect preterm labor to enable timely treatment.
(See page 45.)

Improved Suit for Protection During Abrasive Blasting

In contrast to earlier suits, this suit can be donned faster, requires no special undergarments, needs no respirator, eliminates the need for showering after abrasive blasting, and needs no laundering prior to reuse.
(See page 62.)

Exoskeletal System for Neuromuscular Rehabilitation

A system of sensors and actuators for the lower extremities of human patients and astronauts is under development to serve diverse purposes in neuromuscular research and rehabilitation. The design is guided by the findings that show that patients with injured spinal cords can relearn how to walk.
(See page 62.)

single-crystal yag reinforcement preforms for refractory composites

Preforms of YAG fibers can now be readily fabricated in net size and shape, with tailored orientation of the fibers. These preforms can serve as fiber reinforcements in certain composite materials that withstand temperatures as high as 1,700 °C.
(See page 65.)

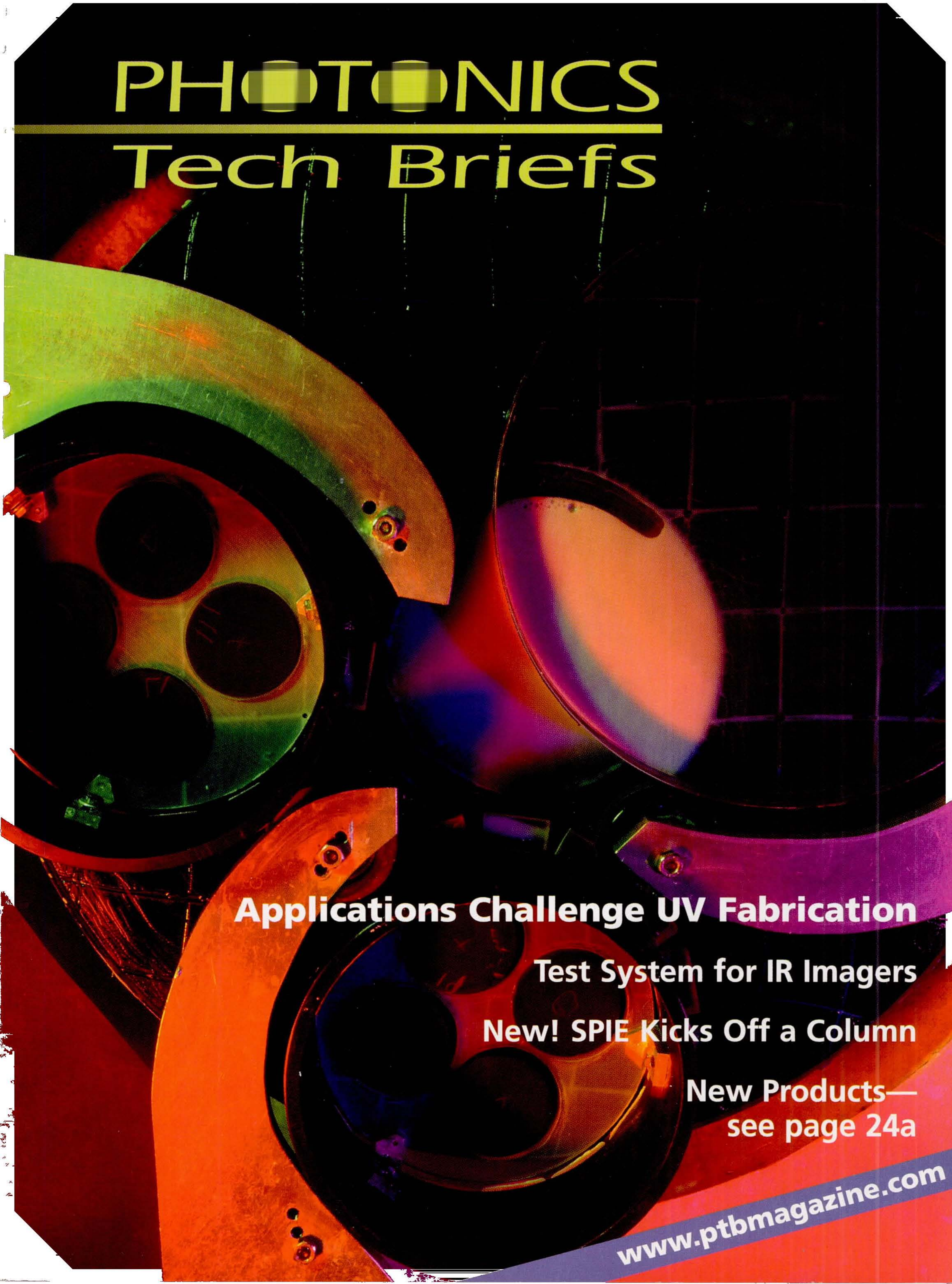
Inflatable Membrane Reflectors for Multiple-Purpose Applications

Experiments demonstrate the feasibility of inflatable reflectors with very low system aerial densities. Diverse applications include radio and optical communications, telescopes, and the concentration of sunlight for power generation.
(See page 69.)

Ceramic Composites of ZrB_2, HfB_2, ZrC, HfC, and SiC

Improved ceramic composites have been invented in an effort to obtain better resistance to ablation at high temperature. Potential applications, other than thermal protection of spacecraft during the reentry into the Earth's atmosphere, include laboratory and industrial processes involving hot oxidizing gases.
(See page 74.)

PHOTONICS Tech Briefs



Applications Challenge UV Fabrication

Test System for IR Imagers

New! SPIE Kicks Off a Column

New Products—see page 24a

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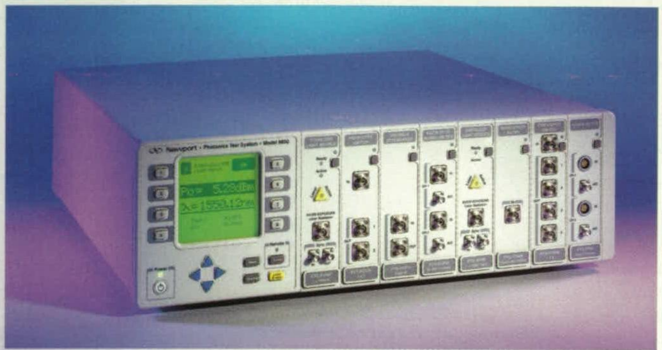

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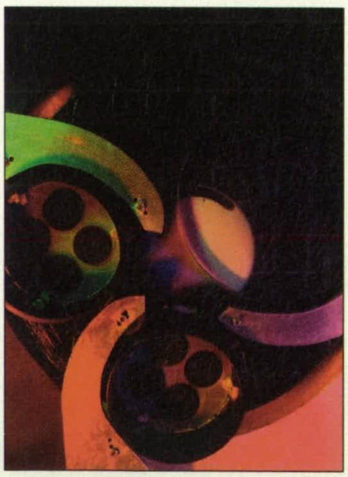
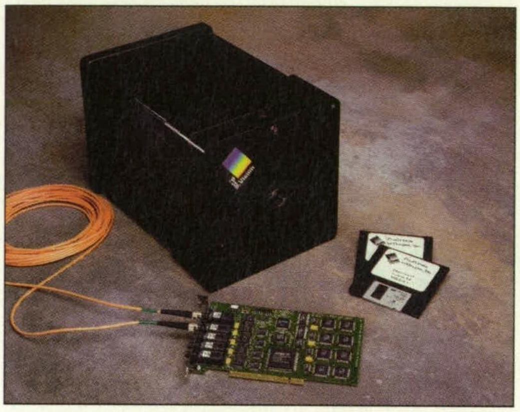


On the Cover: Meeting both shape and surface-quality specifications in polishing of deep-UV optics requires a delicate balancing act between the various process parameters. Cover image courtesy of Alpine Research Optics.

Photonics Tech Briefs 1998 Readers' Choice Product of the Year

Readers' votes for *Photonics Tech Briefs'* 1998 Product of the Year have been tallied, and the winners are:



Gold Winner

and Product of the Year:

PixelVision (Beaverton, OR) AdaptIII™ CCD Camera, designed for high-performance imaging at rates of up to 10,000 frames per second

Silver Winner

BEI Sensors & Systems Co. (Sylmar, CA) LIE5 Optical Linear Encoder, with flip-chip-on-glass optics and built-in interpolation circuitry yielding resolutions as fine as 0.1 micrometer

Bronze Winner

Synrad (Mukilteo, WA) Digital Laser Marking Kit, based on the Synrad DH Series 125-W sealed RF-excited CO_2 laser marking head

Other finalists include Photon Inc. (Santa Clara, CA) Goniometric Radiometer for laser diode measurement; Berkeley Nucleonics Corp. (San Rafael, CA) Model 625A SmartARB Signal Generator; and Lasiris Inc. (St.-Laurent, Quebec, Canada) LPM Series Long Phase Mask

Winners were chosen by reader vote on *Photonics Tech Briefs'* web site from among the six Products of the Month nominated by the editors during 1998. The awards will be presented at a ceremony at CLEO '99 in Baltimore late this month.

SPIE

The Power of Light

With this issue Photonics Tech Briefs *inaugurates a regular column to be contributed by SPIE — the International Society for Optical Engineering — that will enable the reader to better understand the mission and purpose of the association and the scope of its activities.*

What is SPIE?

From its origins in 1955 as the Society of Photo-Optical Instrumentation Engineers, SPIE—the International Society for Optical Engineering—is the largest international professional society serving the practicing engineer and scientist in the fields of optics and photonics. The Society serves the global technical and business communities with more than 13,000 individual, 310 corporate, and 3,000 technical group members in more than 74 countries worldwide.

SPIE exists to serve its members and the worldwide technical and economic communities with which its members interact. The Society accomplishes this mission primarily by bringing information on the latest technological breakthroughs and their application to thousands of individuals and organizations.

Among the many services the Society offers are the sponsorship, planning, and execution of technical conferences, product exhibitions, and symposia; the publication and distribution of archival professional journals, conference proceedings, newsletters, and optics-related texts and monographs; and the development and delivery of professional continuing education programs, some live via satellite or other electronic means.

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Applications CHALLENGE

Optical Fabrication

Understanding failure mechanisms enables production of laser optics with higher damage resistance and longer operating lifetime.

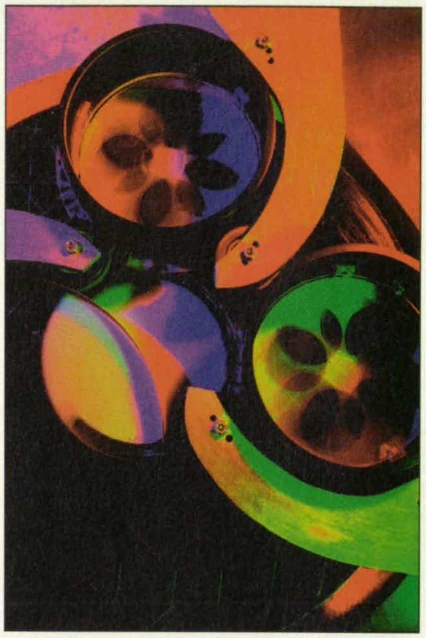
Optics for the deep ultraviolet (below 250 nm) is a rapidly growing field. To date, this growth has been primarily driven by excimer-based applications such as microlithography, photorefractive keratectomy (PRK), laser-assisted *in-situ* keratomileusis (LASIK), laser marking, and various micromachining tasks. Recently, however, solid-state UV lasers have also become available; these promise to generate further market expansion by enabling a new range of applications.

Producing optics that can withstand prolonged exposure to intense UV radiation has presented a number of challenges to manufacturers. Over the past few years, intensive research and testing have yielded fabrication methods enabling a significant increase in the lifetime of excimer laser components. However, the different output characteristics of excimer and solid-state lasers result in somewhat different damage mechanisms. It is not yet clear if the techniques developed for excimer laser optics will be applicable in the solid-state regime, because of their different damage mechanisms. This article will review what has been learned about long-life excimer laser components and discuss the probable direction of future work on solid-state UV laser optics.

UV Damage

Excimer lasers are pulsed sources that produce light at the UV wavelengths of 351, 308, 248, 193 and 157 nm. The most powerful excimer lasers produce up to about 200 W of total power, with repetition rates in the 100-Hz to 1-kHz range, and pulse lengths of tens of nanoseconds. The output beam from an excimer laser is rectangular, with a smallest dimension of at least 10 mm. The intensity profile is fairly homogeneous, and free of hot spots (localized areas of high intensity). Because its wavefront quality is far from diffraction-limited, an entire excimer laser beam cannot be easily concentrated into a small spot. This fact keeps the peak fluences normally encountered in a subsequent optical train fairly low, generally in the 0.1- to 5-J/cm^2 range.

Because of these moderate fluences, the failure mechanism in optical components used with excimer lasers is not usually catastrophic surface damage. In fact, the actual mechanism of damage is often impossible to clearly identify. A gradual decline in performance (*e.g.,* reflectivity for a mirror) is observed as the total accumulated pulse count increases. The component typically ceases to perform adequately before catastrophic failure occurs. With no single damage event, it has become standard in both the microlithography and PRK industries to define a 5% decrease in reflectivity as failure for an excimer laser mirror. At the present time, it is possible to produce excimer optics that can withstand well over one billion pulses before failing.



Meeting both shape and surface-quality specifications in polishing of deep-UV optics requires a delicate balancing act between the various process parameters.

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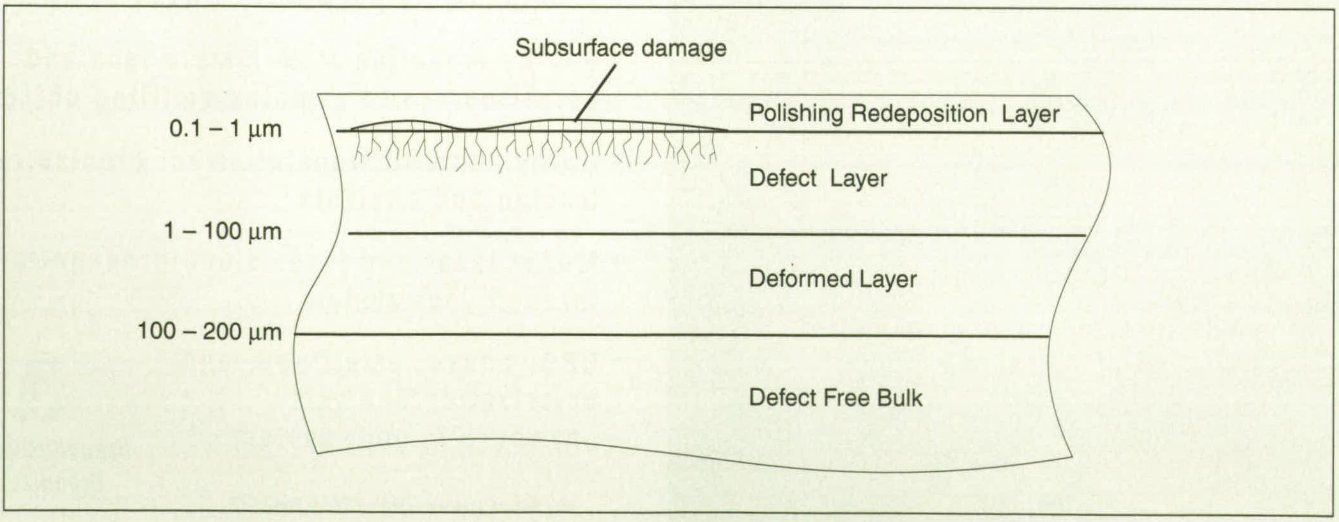


Figure 1. Schematic of subsurface damage.

One distinct mechanism limiting laser damage resistance that has been identified is subsurface damage (SSD). Work performed at Lawrence Livermore National Laboratory has shown SSD to consist of fractures and scratches (see Figure 1) caused by the various grinding and polishing processes, which become partially or totally hidden during subsequent fabrication steps. It is theorized that a so-called polishing redeposition layer, which is a thin layer of the substrate material that actually flows while the piece is being worked, covers these defects and seals them below the final polished surface. SSD has the potential to reduce damage threshold by providing a place for light-absorbing contaminants to reside, by allowing atoms at or near the fractures to be more easily ionized, and by causing local intense modulations in the electromagnetic field.

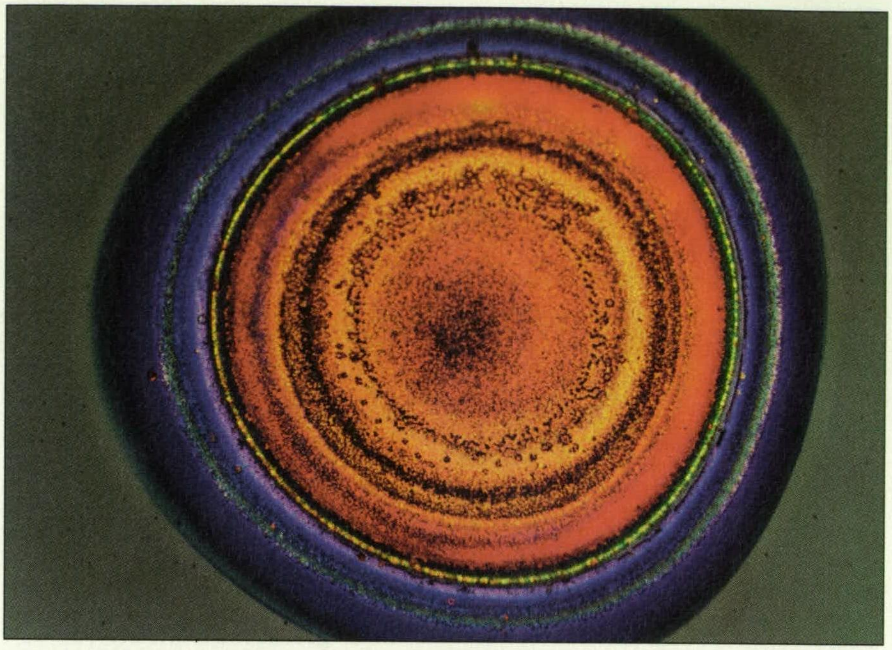
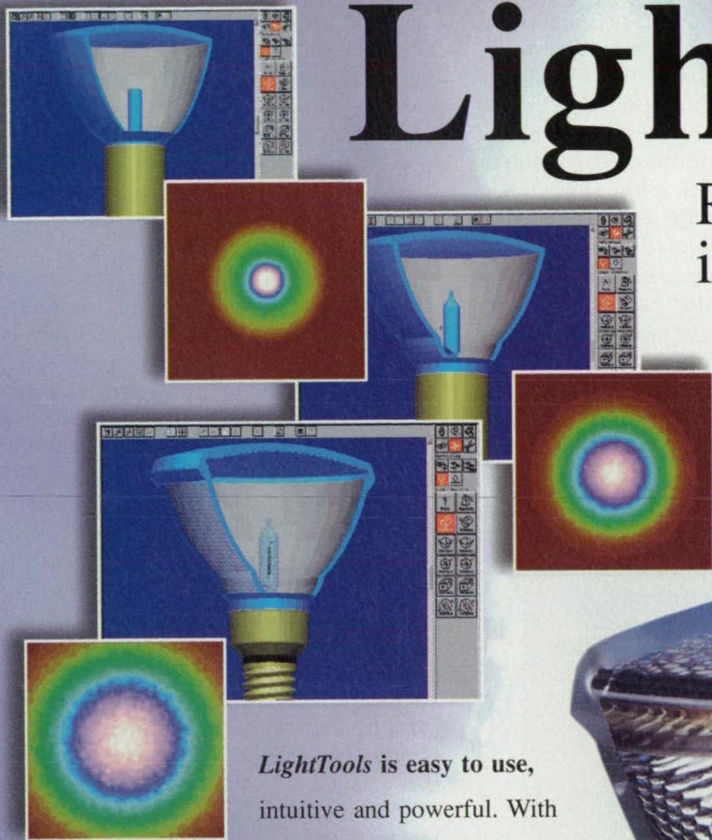


Figure 2. Nomarski DIC micrograph of damage induced by ArF_2 at 193 nm. Photo courtesy of Spica Technologies Inc.

Damage can also occur when residual polishing compound left on the part from fabrication absorbs UV laser light and heats up. But, it is very difficult to entirely remove all traces of polishing compound from a surface. This material adheres to the part's surface and can also work its way into microfractures and surface defects. In these latter instances, it becomes virtually impossible to remove through cleaning.

Optical Fabrication

Alpine Research Optics (ARO) has been producing high-damage-threshold UV laser optics for eight years. In that time, we have found no single magic bullet that eliminates laser damage. Rather, incremental lifetime improvements have come by combining a number of individual techniques. For example, our approach to minimizing SSD is to use a sequence of successively finer grinding



and polishing steps. Each step removes sufficient material to eliminate any damage caused by the previous step. Another important change has been to utilize polishing compounds other than the commonly used ceria (CeO_2). Ceria absorbs strongly at short wavelengths, and any residual ceria on a part can quickly lead to damage.

The only two materials that make suitable substrates for the fabrication of transmissive optical elements in the deep UV are fused silica, which transmits down to about 190 nm, and calcium fluoride (CaF_2), which extends down to around 130 nm. One of the most basic lifetime-limiting factors with both of these substances is bulk material absorption. Absorption leads to heating, which can directly damage a component. Absorption is a much more significant problem for fused silica than CaF_2, because the latter has both a significantly higher coefficient of thermal conductivity as well as a lower thermal coefficient of refractive index. The result is that CaF_2 heats up more slowly than fused silica, and experiences a smaller optical change when it does heat up.

Another bulk material problem that occurs with extended exposure to deep UV light, especially at wavelengths of 193 nm and below, is color-center formation. Color centers are lattice defects that exhibit increased absorption. For fused silica, prolonged exposure to intense deep-UV light can also produce a phenomenon known as densification. This is an actual physical shrinkage, accompanied by an increase in the index of refraction, in the region of exposure. While densification does not necessarily damage a component, it can significantly change its optical properties, thus rendering it useless in a system.

Unfortunately, the processing of calcium fluoride presents several unique challenges. CaF_2 is anisotropic, hygroscopic, and very prone to chipping and fracturing. During polishing, small particles can break loose from the substrate edge and be dragged over the surface, producing scratches. Eliminating these scratches requires lengthening the polishing time. Unfortunately, the longer the polishing time, the more difficult it is to hold a given flatness or surface figure.

Thus, fabricating CaF_2 components requires a very delicate balancing act between the various process parameters (polishing time, spindle speed, spindle pressure, etc.) in order to simultaneously meet both shape and surface quality specifications. In this connection, we have found that the use of pad polishing, as opposed to conventional pitch laps, can speed up the process, making it easier to achieve tight surface quality specifications. Probably the most important step we have taken, however, is simply to environmentally isolate the polishing area for CaF_2, completely preventing any cross-contamination from our fused silica polishing procedures.

Considerable development has also been achieved on the optical coatings, especially for use at 193 nm. The main problem at this wavelength is the limited number of adequately transmissive materials. We have found that various fluoride materials produce thin films with the best combination of optical and mechanical characteristics. We have also determined that conventional E-beam evaporation is the most effective deposition method for these materials. Ion-assisted deposition, which can create high-density, high-damage-threshold coatings at visible and IR wavelengths, sometimes produces oxides that are absorptive in the UV.

UV Solid-State Lasers

Solid-state UV lasers typically function by frequency-multiplying the fundamental wavelength of a laser crystal, usually Nd:YAG or $Nd:YVO_4$, which both have a fundamental of 1.064 μm. This leads to multiplied output at the third (355 nm),

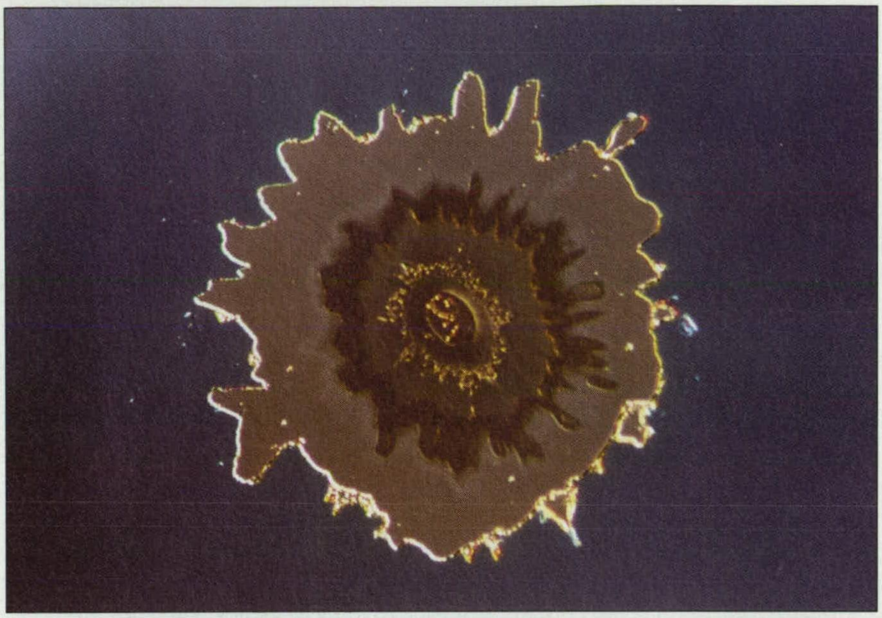


Figure 3. Nomarski DIC micrograph of typical damage induced by a Q-switched infrared laser. Photo courtesy of Spica Technologies Inc.

fourth (266 nm), and fifth (213 nm) harmonics. Both CW and pulsed operation are possible, with pulse repetition rates usually in the 1-kHz to 10-kHz range. The total UV pulsed power available from solid-state lasers is much smaller than from excimer lasers, with a typical maximum of about 5 W. However, they can have pulse lengths of just a few nanoseconds, so that the peak power can be quite high. Furthermore, solid-state lasers tend to have inhomogeneous beams, exhibiting hot spots of very high fluence. Finally, solid-state lasers can produce excellent mode quality (TEM_{00}), meaning that the beams can be easily concentrated into small focused spots. As a result, solid-state laser optics can routinely expect to experience peak fluences in the 10 to 50 mJ/cm^2 range, a value much higher than for excimer laser optics. Also, the higher repetition rates of solid-state lasers mean that their optics can quickly accumulate a very large total pulse count. Figures 2 and 3 show differences in damage mechanisms.

These unique characteristics lead to different damage mechanisms from those experienced with excimer lasers. The high peak fluences can literally blast a small hole in an optical coating or surface. For a typical beam diameter of about 1 mm, damage sites of 100 to 200 μm in size generally occur. Several of these may accumulate before the optic becomes unusable. Under certain circumstances, optics for solid-state lasers may also exhibit a gradual performance deterioration. This happens when dust or another contaminant settles on the optics surface. A high-fluence pulse may ablate this contaminant, leaving a very small damaged area in its wake. This damaged area, which is usually in the 10-μm size range, then scatters incident light, thus reducing the efficiency of the optic. A buildup of such damage sites over time will cause an appreciable reduction in component performance.

Extensive testing is now being performed by organizations such as Lawrence Livermore National Lab (as part of the National Ignition Facility program) to determine the effect of various process techniques on UV solid-state laser damage resistance. One promising approach appears to be the use of superpolishing methods, where the optic is typically fully immersed in the polishing slurry (a mixture of water and abrasives). As the polishing progresses, the slurry is gradually thinned until it becomes essentially just water. Superpolishing results in optics with very low surface roughness, which may raise the peak fluence levels that the part can withstand.

In recent years, tremendous progress has been made in extending the lifetime for excimer laser optical components. Now, the emergence of solid-state UV lasers, with much higher peak powers and repetition rates, has raised the performance bar once again. Through cooperation among sophisticated testing facilities, laser and component manufacturers, and systems integrators, ARO confidently expects to meet the need for long-lifetime optical components for these lasers.

For more information, please contact David Collier or Wayne Pantley at Alpine Research Optics, 3180 Sterling Circle, Boulder, CO 80301; (303) 444-3420, Fax (303) 444-1686, E-mail: AROcorp@AROcorp.com, www.optics.org/arocorp/.

a Turnkey Test System for IR Imagers

With IRWindows™, the months-long task of creating an automated test is reduced to literally minutes.

Infrared imaging systems, the see-in-the-dark marvels that performed so well in Desert Storm, have historically been produced in small quantities, primarily for military customers. But new low-cost technologies and the economics of large-scale production have made these devices available to commercial customers, for tasks ranging from the mundane, such as troubleshooting steam pipes, to the exotic, such as night vision for cars. Along with these changes, a new challenge has emerged: the need for quick, repeatable, accurate, low-cost testing of the IR imager.

In the low-volume high-dollar military market, it was practical to have experienced and knowledgeable personnel, typically part of the engineering team, involved in the testing of the production systems. For small quantities, testing could be done manually: the operator would position the correct target in front of the blackbody, set the blackbody temperature, wait for the system to settle, take a data point by observation of unit under test (UUT) output, and repeat the process for the next data point. This is a slow, tedious, error-prone process that relies on trained and experienced observers to accurately interpret the imager output. For larger production quantities, automated testing needed to be developed. In addition to faster testing, an automated test system could help eliminate operator error both in the operation of the equipment and in the recording and reduction of test data.

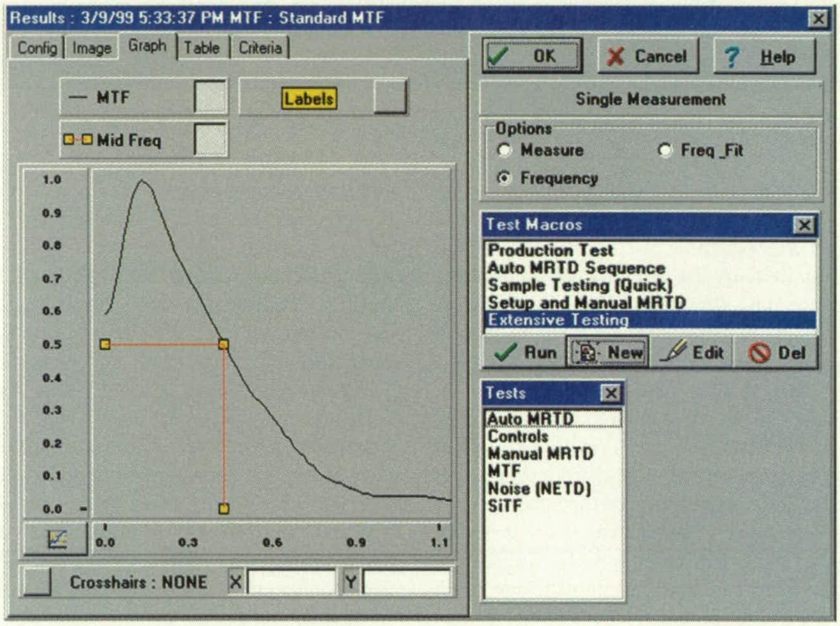


Figure 1. Typical MTF curve produced by IRWindows™.

Figure 2. Turnkey IR target projector.

Bob Nicklin, senior systems engineer for industrial automotive IR products at Raytheon TI Systems, in Dallas, TX, has implemented automated test systems for several IR imaging programs at Raytheon. "Repeatability, accuracy, quality, and operator independence are all as much a concern for us as speed," Nicklin said. "Manual testing imposes a boring, repetitive task on an operator, and we can't get the consistent overall product quality that we're committed to delivering. The time saved is an obvious tangible benefit, but these less tangible effects are important."

The obstacle to automated testing, however, was the time and expense of

developing the test system. The process looked something like this:

- Specify and purchase a properly sized blackbody, target wheel, and collimator. Determine an appropriate set of target styles and sizes.
- Buy a computer, an IEEE-488 interface card to communicate with the test equipment, and suitable hardware interfaces to read the data output from the UUT.
- Get everything to work together: Install the IEEE-488 and data capture cards, along with their associated drivers, in the computer. Learn the interface message set for the blackbody and target wheel, and then write and debug the code to adapt the driver software to these instruments.
- Research the principles behind each functional test to be implemented (modulation transfer function, minimum resolvable temperature difference, etc.) and then create the algorithms for each test, using an appropriate programming language. Debug the algorithms. Exhaustively verify the test results from these algorithms against manual test data from many different UUTs.
- Create a user interface so that the program can be used by someone other than the programmer.
- Compose and format reports to present test results in a clear and understandable fashion.

Several man-years could be expended on the development of such test equipment. The result, too, would be a specialized test system, suitable only for one type of imaging system. Since development time was limited and the target audience small, the user interface was typically rudimentary—difficult to learn and use. To add a new test or modify an existing one, the software engineer would have to be tracked down and scheduled to rewrite some of his code. When a new imaging system needed testing, the process would start all over again.

Santa Barbara Infrared (SBIR) Inc., of Santa Barbara, CA, a leading manufacturer of infrared test equipment, saw this process repeated time and time again by its customers. One thing that stood out was that the bulk of this process was not UUT-specific: with sufficient planning, the framework for an automatic test system could be designed to be universal, with a relatively small fill-in-the-blanks menu set to allow the test engineer to define the specifics for his particular UUT. This is the basis for their IRWindows™ test software (see Figure 1). Designed to work with SBIR's off-the-shelf target projectors (Figure 2), it provides a turnkey solution for IR imaging testing. With this product, the systems design and integration are already done: the hardware works together, the test algorithms are designed and debugged, and standard reports are already formatted. The designers had the luxury of enough time to develop a really good user interface: for the engineer a versatile and easily configured test set, and for the production line an easy-to-understand and "idiot-proof" execution menu.

An engineer familiar with using other Windows applications can learn how to use IRWindows™ in a few hours.

Continued

A knowledge of programming is not needed. After learning IRWindows™, the months-long task of creating an automated test is reduced to literally minutes. It is actually easier to specify a test in IRWindows™ than to perform the test manually. Additionally, uncertainty about the validity of the test results is no longer an issue.

Nicklin chose to buy IRWindows™ to test Raytheon's new uncooled PalmIR camera. "A capital equipment purchase is so much easier than putting together a test equipment development program," said Nicklin. "Sure, we understand the principles and could create our own test system, but we had more important problems to worry about. Our own hardware is where we need to spend our time." Success with the PalmIR program led Nicklin to implement the same IRWindows™ test system on several other Raytheon camera programs, most recently the Driver's Vision Enhancement (DVE) system (see Figure 3), a night vision camera to be offered as an option in next year's Cadillac DeVille. "We really need automation on DVE," says Nicklin. "We're committed to deliveries of as many as 60 units per day to Cadillac. But it makes sense even for a small program. With the time savings and the improved overall product quality, the software is essentially free."

Figure 3. Driver's Vision Enhancement IR test system.

Automated testing is the better way to test infrared imaging systems. It eliminates operator error, removes reliance on human perception, and generates repeatable and accurate test results. Automated testing is now practical even for the development lab, or the end user, or other applications that do not have the high volume of testing traditionally associated with automatic test systems.

For more information, contact Greg Smoyer at Santa Barbara Infrared Inc., 312 A N. Nopal St., Santa Barbara, CA 93103; (805) 965-3669; fax: (805) 963-3858; E-mail: gsmoyer@sbir.com.

Novel Coating Technology Improves Ball Lenses for Fiber Coupling

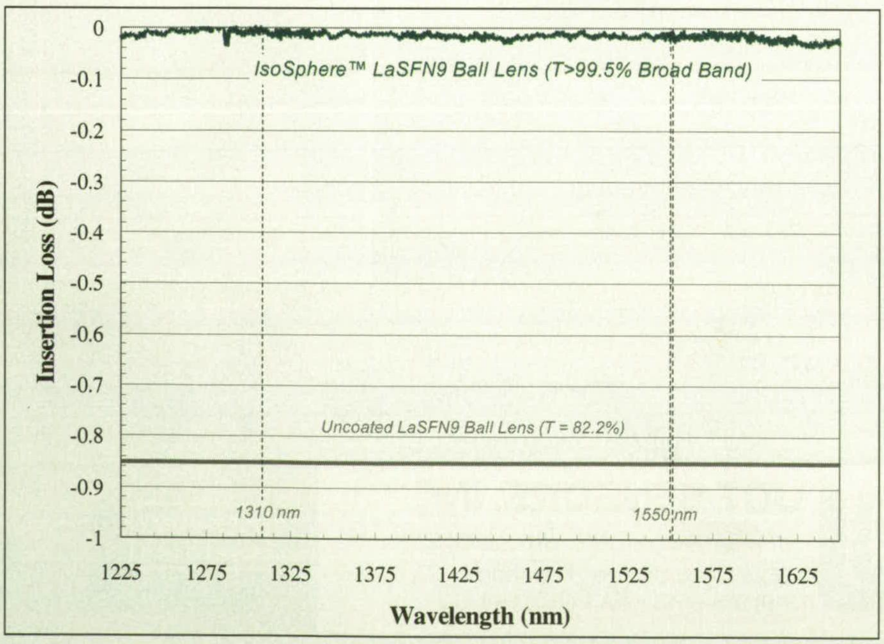
Applying LPCVD technology to optical thin films has enabled production of coatings with superior optical and mechanical characteristics.

Deposition Sciences Incorporated, Santa Rosa, California

Small ball (full sphere) lenses in the 0.5-mm to 3.0-mm diameter range offer a number of practical advantages for fiber-to-fiber coupling and fiber collimation. Ball lenses are more physically compact and less expensive than commonly used gradient index (GRIN) lenses. Furthermore, the complete rotational symmetry of ball lenses makes them easier to mount, position, and align to a fiber than the cylindrically shaped GRIN lenses. Despite these advantages, the wide-scale use of ball lenses in the fiber telecommunications business has been limited, because of difficulties in depositing high-performance antireflection (AR) coatings on these lenses. Specifically, coatings produced using traditional evaporative technology are highly nonuniform; also, the tooling used leaves an uncoated stripe on the part. Together, these factors then require that the micro-ball lenses be precisely oriented during coupler or collimator assembly. In work performed at Deposition Sciences Incorporated (DSI), low-pressure chemical vapor deposition (LPCVD) technology has been adapted to uniformly coat the entire surface of ball lenses. The economics of this process make it viable for the volume production of components for the telecommunications market.

In a traditional evaporative coating chamber, one or more racks hold the substrates to be coated. The first step in the process is to pump all air out of the chamber to achieve a very high vacuum (10^{-6} Torr or better). A succession of coating materials is then evaporated, typically using either resistive heating or electron-beam bombardment. Because the chamber is in near vacuum, the mean free path of evaporated atoms or molecules is several meters. They stream out and recondense onto any surface in the chamber that has a direct line of sight to the source. This process makes the deposition rate highly dependent upon the distance from the source to the substrate surfaces, as well as their relative angular orientation. In order to maximize layer uniformity, the racks are rotated during coating, so that every part experiences the same "average" distance from the source. Complex internal masking is also often used to enhance deposition uniformity throughout the chamber.

There are two significant drawbacks to applying this evaporative technique to coat small ball lenses. First, highly curved ball lenses cannot be coated uniformly because of the significantly different orientation that the center and edge of each lens has with respect to the coating source. Second, processing an entire ball requires coating one side first, and then turning the balls 180° and repeating the procedure to coat the second side. Furthermore, in order for the chamber tooling to securely hold a ball lens, it must cover slightly more than half the sphere, so the end result is an uncoated stripe that runs around the entire circumference of the finished part. Together, these factors require that the tiny ball lenses be precisely oriented during the assembly process to ensure that the right part of the coated surface is facing correctly.



Transmission of a dual-wavelength (1310 nm and 1550 nm) IsoDyn coating showing less than 0.01 dB loss per surface for a total loss of 0.02 dB.

To successfully address this coating problem, DSI has developed a form of LPCVD, called IsoDyn™, that avoids the limitations of evaporative technology. LPCVD is widely used in the semiconductor industry to produce thin films during integrated circuit production, but had not been widely used for optical thin films.

In the IsoDyn process, parts are placed in an evacuated chamber and heated to about 500 °C. The chamber is then filled with a chemical vapor at relatively high (usually 0.1 to 5.0 Torr) pressure. The heat causes a chemical reaction in the precursor gas, resulting in deposition of the desired substance on all exposed surfaces of the substrate. This procedure can be repeated using various precursor gases to build up a multilayer coating.

The high gas pressure results in a short mean free path for the gas molecules, causing deposition to occur at the same rate on every surface within the chamber, regardless of its position or orientation. Consequently, this technique can produce extremely uniform coatings on highly curved or unusually shaped parts. Furthermore, there is no need to hold parts in traditional tooling and move them during the coating process. The lack of tooling that masks off some of the part during coating enables the production of uniform thin films covering virtually the entire surface of ball lenses.

Another benefit of the IsoDyn process is that the entire volume of the reactor can be filled with parts, and all surfaces of a part can be coated in a single run. This translates directly into higher throughput, and hence lower production cost.

Continued

DSI is now utilizing IsoDyn coating technology to produce a range of ball lenses for telecommunications, called IsoSpheres™, including BK 7, spinel, sapphire, LaSF N9, LaSF N18, LaSF N35, and stabilized cubic zirconia. The standard multilayer coating for these products has a specified insertion loss of less than 0.01 dB per surface at either 1310 nm or 1550 nm. A dual-wavelength antireflection coating for both these wavelengths (see graph), as well as other single-wavelength and dual-wavelength combinations, is also available.

This work was performed by Dr. Donald Z. Rogers, Manager, Telecommunications Business Unit, **Deposition Sciences Incorporated,** *Santa Rosa, CA. IsoSphere and IsoDyn are trademarks of the Deposition Sciences Corporation, an Advanced Lighting Technologies Company. For more information call (707) 573-6742, fax (707) 579-0731 or E-mail don.rogers@depsci.com.*

Two-Axis Reflective Device for Image Stabilization and Beamsteering

A fast steering mirror is low in cost and has many applications.

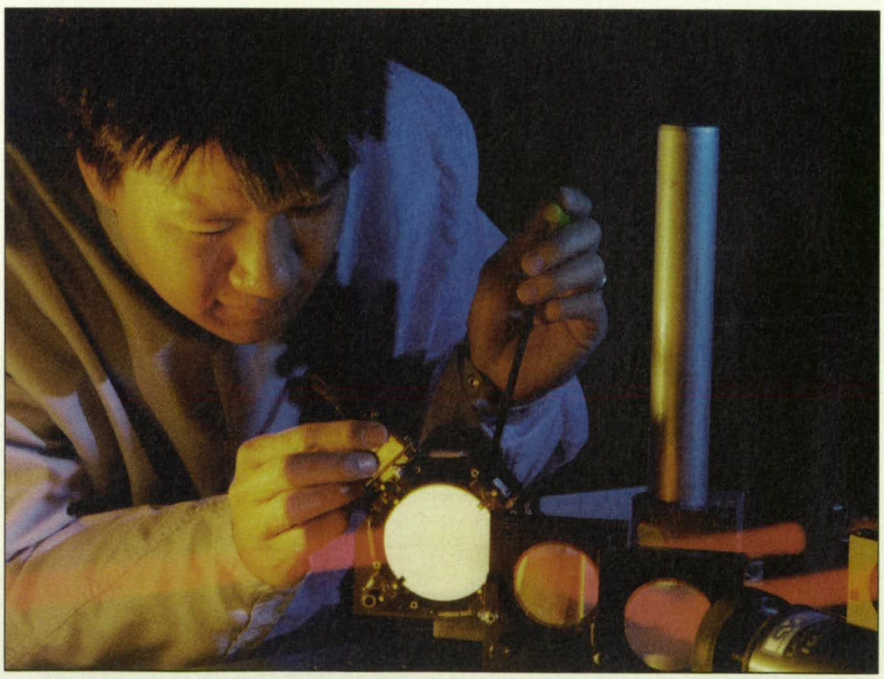
Ball Aerospace and Technologies, Boulder, Colorado

Scientists, astronomers, optical researchers, and manufacturers frequently require two-axis reflective optical mechanisms to meet the requirements of robust beamsteering systems. Image tracking, scene scanning, line-of-sight pointing and/or beam stabilization designs often incorporate reduced-performance devices in complex arrangements to constrain costs.

Galvoscanners and piezo motor mechanisms have been employed in the past to accomplish two-axis beamsteering. These devices usually incorporate mirrors attached to separately located and controlled tip-and-tilt structures, which introduce several disadvantages in the realms of beam orthogonality, alignment stability, and heat dissipation, as well as problems with the generally limited area available in optics layouts. Combined tip-and-tilt mechanisms are generally available but tend to be very expensive. Custom systems complete with electronic stabilization filters and reaction masses may increase the price to several hundred thousand dollars.

Ball Aerospace and Technologies Corp. recently introduced a low-cost two-axis fast steering mirror (FSM). The operation of this design, based on technology developed over a 15-year period, depends on a synergistic combination of five components: mirror, suspension, actuators, sensors, and control electronics.

Continued



Ball Aerospace engineers use two **Fast Steering Mirrors** to validate a laser pointing and tracking device in the laboratory.

The mirror is available as an aluminum, beryllium, or glass substrate. Metal mirrors are light in weight to reduce inertia and to provide optimal dynamic performance via high-efficiency actuators and high-bandwidth position sensors. The reflective surface of an aluminum mirror is produced by diamond turning; an optical coating is applied to allow for cleaning and to provide selective spectral performance. Beryllium mirrors are nickel-plated and polished. Glass mirrors are user-replaceable, with a variety of flatness and coating options; they provide the least expensive option and greatest flexibility, but with some reduction in performance.

The mechanism's design differs from other technologies in that its unique suspension provides two-axis rotation about the center front surface of the mirror. The FSM can be substituted for a folding mirror to yield dynamic steering and/or angular adjustment in the optical train.

Lorentz-force (voice-coil) actuators are used in pairs to produce diametrically balanced "push-pull" forces on the mirrors' opposite edges.

Passive permanent-magnet armature sections are placed on the mirror; no heat is produced by the motor coils directly on the substrate, and no wiring is required on the moving mechanism. The minimal heat from the highly efficient actuator motor coils is dissipated into the FSM assembly's base.

Mirror position is derived from custom differential eddy-current sensors that achieve exceptional resolution and repeatability. Measurement signals are generated and demodulated in electronics housed in the assembly base. The position sensor output is returned to the control electronics to achieve local high-bandwidth servo control.

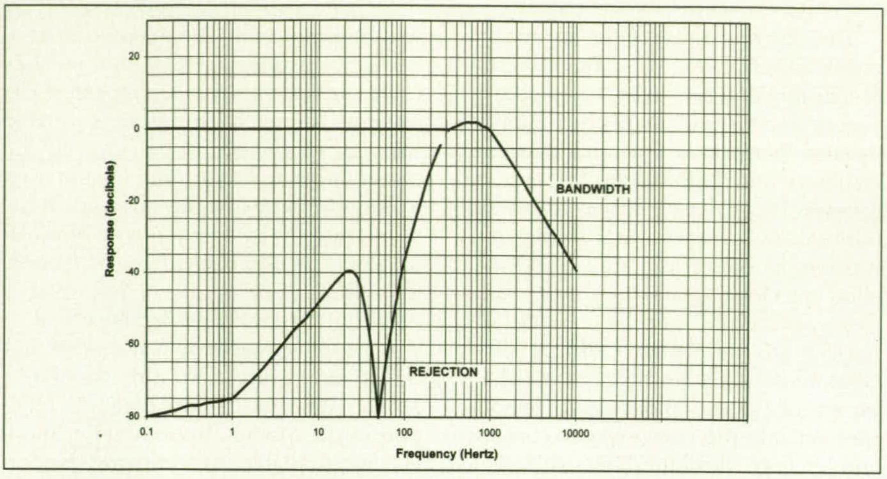
Modular electronics provide for two-axis commands from the user. The response to user commands emanates from closed-loop servo control, consisting of the mirror's angular position and feedback into an internal loop with compensation.

In the laboratory test setup shown in the photograph, Ball engineers use two FSMs to validate a laser pointing and tracking hardware design and control algorithm developed to detect and compensate for small deviations in a received optical signal. FSM commands are generated, which null the effects of mechanical jitter or vibration on the optical signal introduced by satellite platform disturbances. Bandwidths above 500 Hz with submicroradian accuracies have been achieved.

The fast steering mirrors are also in use in a Daylight Tracking System located at the Starfire Optical Range in Albuquerque, NM. The mirrors are controlled by a digital system that receives error signals from a high-speed CCD camera. The track bandwidth is variable from 20 to 100 Hz, depending on the camera's coadd factor. The FSM is used to remove line-of-sight angular deviations caused by atmospheric gimbal-mount and seismic disturbances. Closed-loop RMS track errors of less than 1 microradian have been demonstrated.

A typical closed-loop bandwidth and disturbance rejection plot for Ball's Model 3B is shown in the figure. In addition to the Model 3B, three other models are available with varying performance specifications. The most recently added, the Model 3G, features a user-removable and replaceable glass substrate, allowing for easy cleaning or replacement. The notion of disposable optics can easily be entertained with this configuration. Glass substrate mirrors also offer the flexibility of interchangeable elements and reduced cost.

Recent applications for FSMs have been found at the Naval Research Laboratory at Flagstaff, AZ; Boeing North American, Autonetics Electronic Systems Division, Anaheim, CA; Goddard Space Flight Center, Greenbelt, MD; Boeing Company Defense and Space Group,



A typical **Closed-Loop Bandwidth and Disturbance Rejection Curve** for the Ball Aerospace Model 3B fast steering mirror.

Redstone Arsenal, AL; SVS R&D Systems Inc., Albuquerque, NM; and Boeing North American, Rocketdyne Technical Services Division, Kihei Maui, HI.

This work was done by Albert Berta, product manager for commercial fast steering mirrors, and associates for **Ball Aerospace and Technologies Corp.** *in Boulder, CO. For more information Berta may be reached at (303) 939-5566; fax: (303) 939-6862; E-mail: aberta@ball.com; www.ball.com/aerospace/fastmir.html.*

Making Curved Diffractive Optics by E-Beam Lithography

Substrates need not be flat, and grating lines need not be straight.

NASA's Jet Propulsion Laboratory, Pasadena, California

Electron-beam (e-beam) lithography has shown promise as a technique for fabricating diffractive optical elements on nonflat substrates. Such optical elements could include convex or concave diffraction gratings with curved grating lines, for use in imaging spectrometers or other scientific instruments operating at wavelengths from ultraviolet through midinfrared.

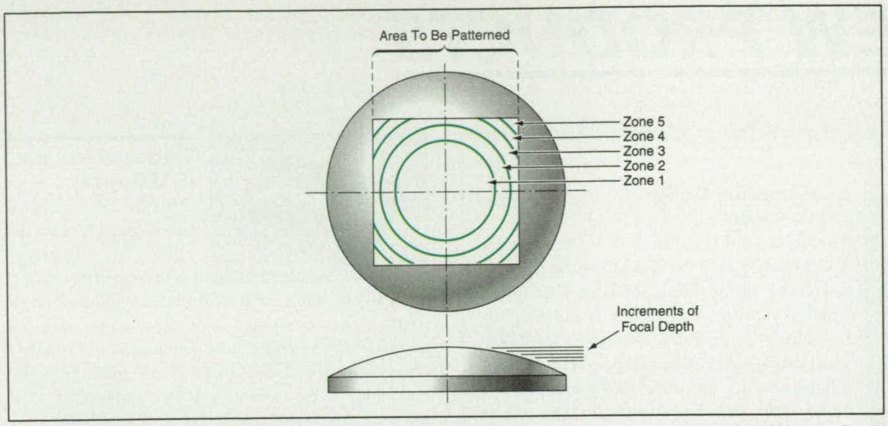
Heretofore, diffractive optical elements made, variously, by diamond ruling and optical holography have been available commercially on flat substrates only. The lines in these gratings have been straight or else have had modest, regular curvatures at most. In contrast, diffractive optical elements made by electron-beam lithography can have arbitrary line shapes and/or arbitrary phase functions.

The present electron-beam-lithographic technique is an extension of another, recently developed electron-beam-lithographic technique for writing phase holograms into thin films of poly(methylmethacrylate) on flat substrates. By patterning and otherwise controlling the electron-beam exposure and monitoring the development/etching process until precise depths are achieved, one can adjust optical phase delays to a precision of less than 1/50th of a wavelength, within 0.5-μm-square regions. Devices produced by use of this technique on flat substrates include Fresnel lenses, arrays of Fresnel lenslets, gratings with both straight and curved grooves, holograms that yield gray-scale images, and patterns for free-space optical interconnections.

Application of the technique to a concave or convex substrate (see figure) involves the following sequence of steps:

1. Establish a grid of points on the substrate.
2. For each grid point, determine the electron-beam-apparatus focus, rotation, and deflection calibration values.
3. From the values obtained in step 2, determine the depth of focus over which patterning errors can be considered negligible, and use the depth-of-focus information to define depth zones.
4. Partition the exposure pattern into subpatterns — one subpattern for each depth zone.
5. Using the electron-beam apparatus, expose each depth zone according to its subpattern. Readjust the apparatus, as needed, when proceeding to the next subpattern.

The technique has been demonstrated by using it to form a small prototype



A **Substrate To Be Patterned** by electron-beam lithography is partitioned into zones of different focal depth, in essentially the same manner in which elevation contours are formed on a topographical map. An electron-beam subpattern exposure is then performed in each zone.

diffraction grating on a convex spherical substrate. In a test, the grating exhibited a first-order-diffraction efficiency of 88 percent. There was no evidence of degradation of the grating by curvature of the substrate. The prototype grating was small. Continuing development efforts are directed toward increasing the patterned area and decreasing the amount of light scattered (as distinguished from diffracted) by gratings of this type.

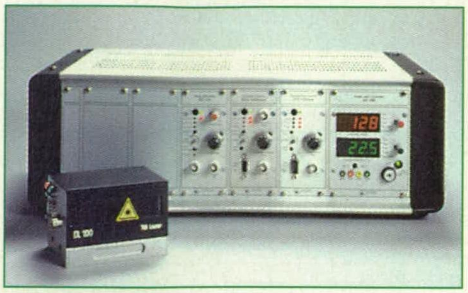
This work was done by Paul Maker, Richard Muller, and Daniel Wilson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Manufacturing/Fabrication category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to: Technology Reporting Office, JPL, Mail Stop 122-116, 4800 Oak Grove Drive, Pasadena, CA 91109; (818) 354-2240.

Refer to NPO-20296, volume and number of this NASA Tech Briefs *issue, and the page number.*

NEW PRODUCTS

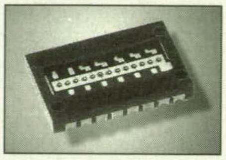
PRODUCT OF THE MONTH



Blue External Cavity Diode Laser

TuiOptics GmbH, Munich, Germany, introduces what it calls the first direct blue external cavity diode laser (ECDL). TuiOptics, which is represented in the U.S. and Canada by Polytec PI, Auburn, MA, offers an ECDL with single-mode transverse and longitudinal output in the 400-nm region. Center wavelength can be chosen in the range between 395 and 405 nm, and the laser is coarsely tunable over more than 2 nm. TuiOptics says that the mode-hopping-free tuning of a few GHz makes the laser usable in high-resolution spectroscopy and the research community.

For More Information Circle No. 760



Thirteen-Element IR LED Array

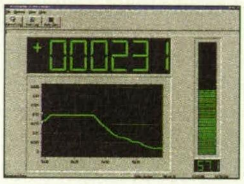
Optek Technology, Carrolton, TX, adds the OPR5013L thirteen-element infrared LED array to its family of hybrid surface-mount components. The company says this component is mechanically and spectrally matched to its OPR5013 phototransistor array, making the pair an ideal choice for 13-bit absolute encoder applications. The polyimide package features an operating temperature range from -55 to +125 °C and wrap-around gold-plated mounting pads compatible with most reflow soldering processes. Optek says the array may be used in any design requiring an IR light source with a wide emission pattern.

For More Information Circle No. 761

5-W Bars & 4-W Fiber-Array Packages at 670 & 690 nm

Coherent Inc. Semiconductor Group (CSG), Santa Clara, CA, now offers high-power visible diode laser bars and fiber-coupled products based on a 1-cm-long 5-W diode laser bar mounted on its industry-standard conduction-cooled package at wavelengths of 670, 680, and 690 nm. CSG also offers a 4-W fiber-array package (FAP), the engine to its microprocessor-based system, the FAP-S. Output of the FAP is an 800-µm-diameter fiber bundle with an NA of <0.16 FWHM. According to Coherent, these products are ideal for medical therapeutics, illumination applications, and pumping of solid-state media.

For More Information Circle No. 762



Measuring and Analysis Package

Capture, a measuring, recording, and analysis package from Pinpoint Laser Systems, Newburyport, MA, is designed for use with precision measuring systems like Pinpoint's own Microgage. The company says the program loads quickly in Windows and is easy to use on the production floor, in the machine shop, the quality control lab, and the field. Measuring units can be scaled in inches, 1/1000 inch, meter, millimeter, micron, and custom units. An auto-zeroing function is available. A signal strength indicator provides a numeric and a graphical display of the signal strength.

For More Information Circle No. 763

Shutterless Cooled CCD Camera System

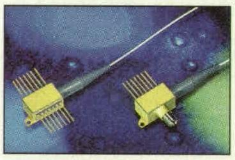
Apogee Instruments, Tucson, AZ, announces the KX85, the newest in its KX Series of cameras for biological imaging. The camera's high-resolution progressive-scan CCD minimizes "shutter" time; images are digitized to 14 bits at 1.3 MHz. The thermoelectrically cooled head has a C-mount for direct coupling to microscopes. A variety of software is available for controlling the cameras, including PMIS, Image-Pro Plus™ from Media Cybernetics®, Maxim CCD®, CCDSoft, KestrelSpec™, and Microsoft Windows™ SLLs with software development kits for integrating the camera into a custom or proprietary environment.

For More Information Circle No. 764

Linear Variable Attenuator

Amphenol Fiber Optic Products, Lisle, IL, makes available a linear variable attenuator, a passive in-line component that precisely reduces the intensity of optical signals with minimum back-reflection. The company says that, unlike competitive products, adjustments beyond upper and lower limits automatically reset without damage. The response function—attenuation dB versus adjustment turns—is linear over its range and operates within many environmental, vibration, and shock conditions. Wavelength ranges include 1285-1330 nm and 1525-1620 nm.

For More Information Circle No. 765



Laser Diodes for DWDM Applications

Mitsubishi Electronics America, Inc., Sunnyvale, CA, announces electroabsorption modulator (EAM) distributed feedback (DFB) laser diodes for dense wavelength-division multiplexing (DWDM) applications. The FU-641SEA Series of integrated EAM DFB diodes meets the 10-Gb/sec transmission speed standard for metropolitan-area Internet and cable broadcast signal distribution applications. The FU-632SEA Series devices meet the 2.5-Gb/sec speed requirement for DWDM, and can cover up to 700-km and 360-km distances for the FU-632SEA-3M and FU-632SEA-6M devices respectively.

For More Information Circle No. 766

DWDM System Analyzer

The new OSA-155 optical system analyzer from Wavetek Wandel & Goltermann, Research Triangle Park, NC, is a dense wavelength-division multiplexer (DWDM) testing device offering measurements of wavelength, power, and optical signal-to-noise ratio for various carriers of multiwavelength signals in the range of 1450 to 1650 nm with 50-GHz/0.8-nm spacing. The company says that conventional spectrum analyzers can determine optical parameters, but do not provide external filter functions for further bit-error analysis. The OSA-155 is fitted with an external monitor output for this application.

For More Information Circle No. 767

Small-Diameter CO_2 Optics

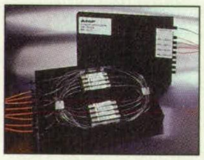
Laser Research Optics, Providence, RI, offers a broad line of small-diameter carbon dioxide laser optics for low-power industrial and medical laser systems. The line includes lenses, turning mirrors, and beam combiners with coatings available for specific phase and polarization requirements. Power-handling capacity is 25-200 W, and the optics are optimized for 10.6-µm radiation where depth of field is important. Sizes range from 0.5 to 1.1 in., and include 15 and 25 mm; focal lengths range from 1-25 in. in half-inch increments. Total absorption value is <0.2 percent.

For More Information Circle No. 768

Portable Laser Marking System

Laser Marking Technologies, Lafayette, CO, introduces the revised LE-100D Series portable laser marking system. This device, based on a diode-pumped solid-state laser, is an enclosed Class 1 Nd:YO_4 unit. According to the company, the system offers high beam quality, elimination of an external cooling system, high peak power, and plug-and-play operation. Laser Marking says the device can provide more than 10,000 hours of continuous operation.

For More Information Circle No. 769



Dense Wavelength-Division Multiplexers

AMP Inc., Harrisburg, PA, says its new line of dense wavelength-division multiplexers (DWDM), add/drop multiplexers, and band-pass WDMs provides a family of devices that allow individual wavelengths to be combined into or separated from a single optical fiber. The line is available in industry-standard 100- and 200-GHz channel spacings for all standard wavelengths within the ITU grid. Four-channel DWDMs are available now, and 8-channel devices will be available in this quarter; 16- and 32-channel DWDMs will follow. The products will come in either a low-profile cassette or a module compatible with AMP ATDU or Lucent LGX distribution hardware.

For More Information Circle No. 770

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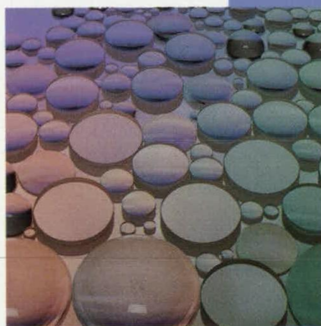

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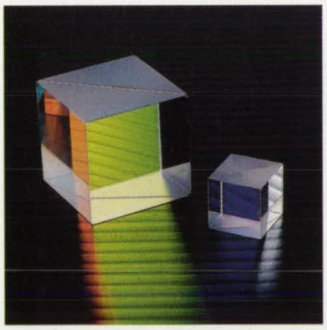

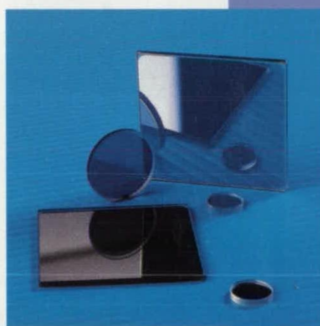

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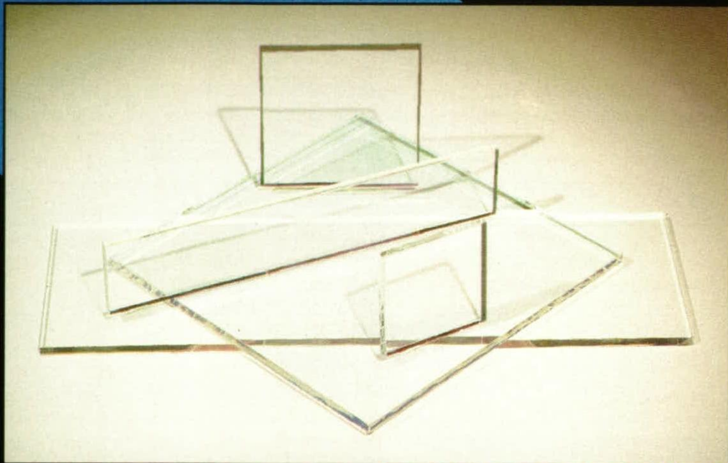

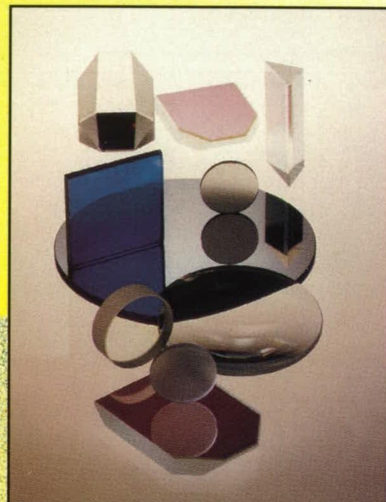

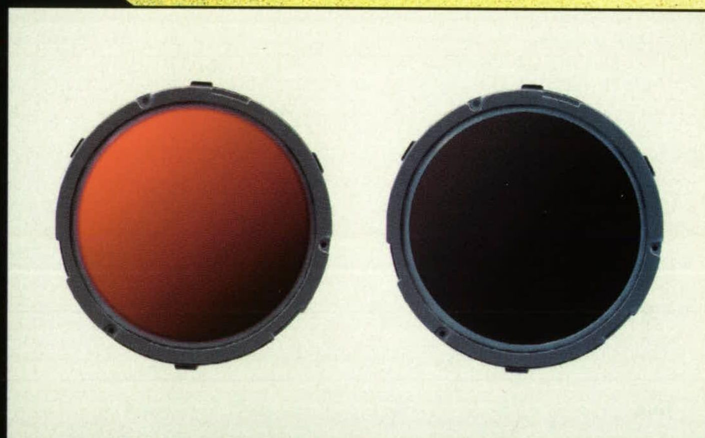

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Rugged Monitors Display Crystal-Growing Data

PanelMount™ flat panel monitors
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Rugged active-matrix color flat-panel monitors from Dolch have passed a challenging test. A pair of PanelMount monitors displayed vital information to crew members in a landmark crystal-growing experiment on the Russian space station Mir, despite rough conditions and erratic power problems. The monitors are now qualified to continue the experiments on future International Space Station missions.

The monitors were used to help unlock the mysteries of proteins, providing clues to the characteristics of these fundamental building blocks of life. Medical researchers used their knowledge of the three-dimensional structure of proteins to design drugs aimed at combating diseases such as cancer, diabetes, and AIDS.

The Interferometer Protein Crystal Growth (IPCG) team selected standard commercial PanelMount monitors for their inherent ruggedness, compact size, and flexible mounting options. The monitors displayed bright, high-resolution graphics from the on-board phase-shift interferometer, according to NASA scientist Bill Witherow. "Our astronaut/scientists were able to track the growth process over a long period, and report their observations of important characteristics as they occurred. We could not have been more pleased with the performance of the monitors," said Witherow.

Marc Murbach, Principal Investigator; Garret Nakashiki; and Mike Jones (left to right) of NASA Ames Research Center assemble the crystal-growing experiment ejector systems.

The Dolch technical support team worked with the IPCG designers on mounting and interfacing issues, and provided special display-screen impact protection against the escape of glass fragments in the event of accidental breakage. Dolch monitors are now certified by NASA as Commercial Off-the-Shelf (COTS) equipment for use in space programs.

For More Information Circle No. 756

Commercial Field Computer Forms Basis of NASA Data Acquisition System

Model 2100 Field Computer System
SoMat Corp.
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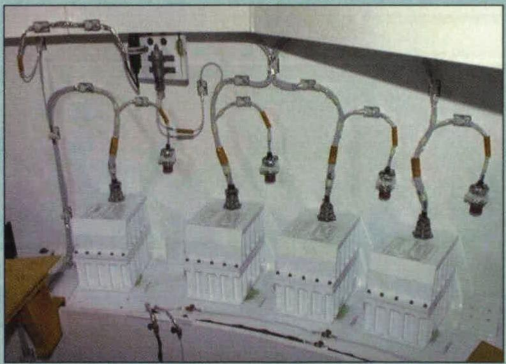
NASA's Marshall Space Flight Center (MSFC), Huntsville, AL, chose a $12,000 commercial field computer from SoMat Corp. as the basis for the Space Shuttle's Solid Rocket Booster (SRB) data acquisition system. The Enhanced Data Acquisition System (EDAS) flies on the SRBs to collect data during booster ascent, descent, and water splashdown. EDAS is used to characterize flight environments in support of planned upgrades to the SRB, and to determine if a redesign of the SRB is necessary to prevent future water-impact damage. The use of the commercial computer system enabled NASA and Boeing North American (NASA's contractor for the shuttle) to design the EDAS in one year, versus the three years required to develop the system from scratch.


Four EDAS units were installed in the forward skirt on the right-hand booster for shuttle mission STS-91 in June 1998.

The SRB is made up of four solid rocket segments plus forward and aft assemblies. During the first two minutes of shuttle ascent, the SRBs provide 80 percent of the shuttle's total thrust. They separate from the vehicle at an altitude of about 28 miles, and parachute into the ocean, aft-first, at 60 miles per hour. The SoMat computer, installed in an enclosure designed and built at MSFC, underwent rigorous tests to ensure its safe operation and durability.

The computer previously had flown on shuttle flights, controlling a camera in the SRB nose cone. The system is powered by three 9-volt batteries, enough power to sample and record data for three hours. The system also is a series of stackable modules, with one module per data channel. The configuration chosen by NASA consists of six modules that monitor strain gauges, accelerometers, and calorimeters.

Four EDAS units were installed in the forward skirt on the right-hand booster for Shuttle Mission STS-91 in June 1998. In its first flight, EDAS started recording six seconds after liftoff. The system recorded data for 10 minutes and then shut down. After the computer was recovered, the data was evaluated by a SoMat program called EASE. NASA plans to fly the EDAS for several flights to achieve a better understanding of the effect of rougher water on the splashdown of the SRBs.

For More Information Circle No. 757

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For More Information Circle No. 537

GPS "Compound Eye" Attitude Sensor

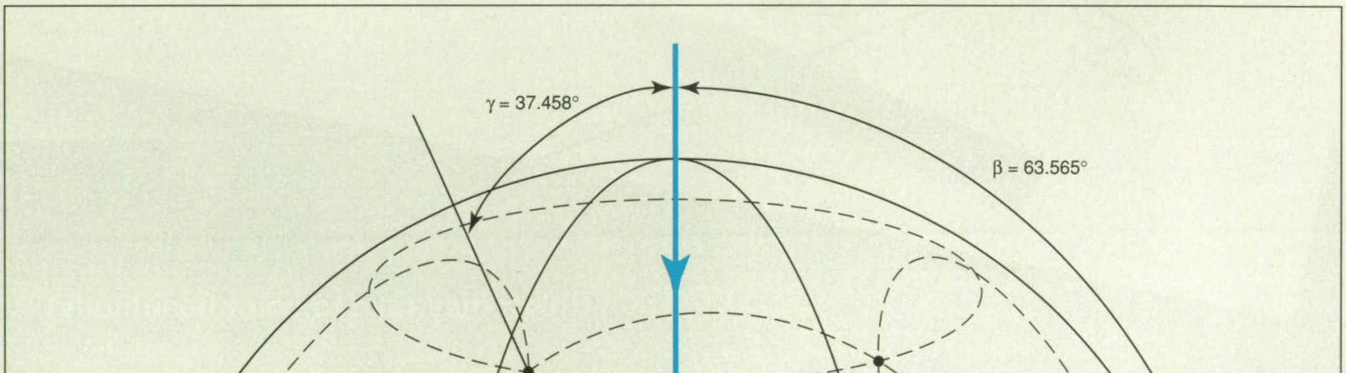
Attitude within several degrees would be determined relatively easily.

Goddard Space Flight Center, Greenbelt, Maryland

A proposed Global Positioning System (GPS) sensor would give information on approximate attitude as well as on position. Unlike other GPS-based attitude sensors, this attitude sensor would not depend on carrier-phase measurements and thus would not be subject to the difficulties and limitations involved in determining attitude from such measurements. Instead, this attitude sensor would be based on a concept that is related to that of an insect's compound eye and that has been implemented in optical attitude sensors of the star-tracker type.

The sensor would be equipped with multiple directional antennas mounted on a convex hemispherical surface. The number of antennas and their locations on the surface would be chosen to obtain a regular or slightly irregular polyhedral (e.g., half-dodecahedral or half-icosahedral) arrangement. Each antenna would thus be aimed to receive GPS signals from a field of view, called a "visualization cone," approximately coincident with the solid angle intercepted by the corresponding face of the polyhedron from the center of the hemisphere (see figure).

By virtue of the conventional GPS function, the positions of the GPS satellites and of the sensor would be known accurately and thus the direction from the sensor to each GPS satellite would be known accurately. Therefore, the reception of a signal from a given GPS satellite or satellites through a given antenna would provide partial attitude information: It would signify that the sensor is oriented so that the visualization cone of the given antenna contains the known direction(s) to the satellite(s). In a similar manner, the simultaneous reception of GPS signals



This **GPS Sensor Would Include Six Antennas** aimed outward from faces of a half regular dodecahedron. Their fields of view would be partially overlapping "visualization cones." The purpose of this arrangement is to deduce the orientation of the sensor from the known location of each GPS satellite "visible" to each antenna.

through the other antennas would make it possible to draw additional conclusions as to how the sensor must be oriented in order to make possible the observed combination of antennas and signals.

The precision of the attitude estimate obtained in this way depends on a number of factors, including notably the number of antennas and the way in which the signal-reception data are processed. Simplistic processing of raw data yields attitude estimates with errors of the order of visualization-cone angles (tens of degrees in the case of a half-dodecahedron). Errors can be reduced by use of optimization techniques in which, for example, greater weights are assigned to signals from directions that lie in overlaps between cones. Errors could be reduced further by increasing the number of antennas to obtain smaller cone angles and overlaps; for example, a first-order calculation has shown that with 16 antennas distributed over the hemispherical surface (on a "buckeyball"), errors would be reduced to <3°. Refinements in processing should make it possible to reduce the errors to the subdegree range.

This work was done by David A. Quinn of **Goddard Space Flight Center** *and John C. Crassidis of Texas A & M University. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center; (301) 286-7351. Refer to GSC-13966.

Compact Magnetic-Sensor Units for Detecting Mines

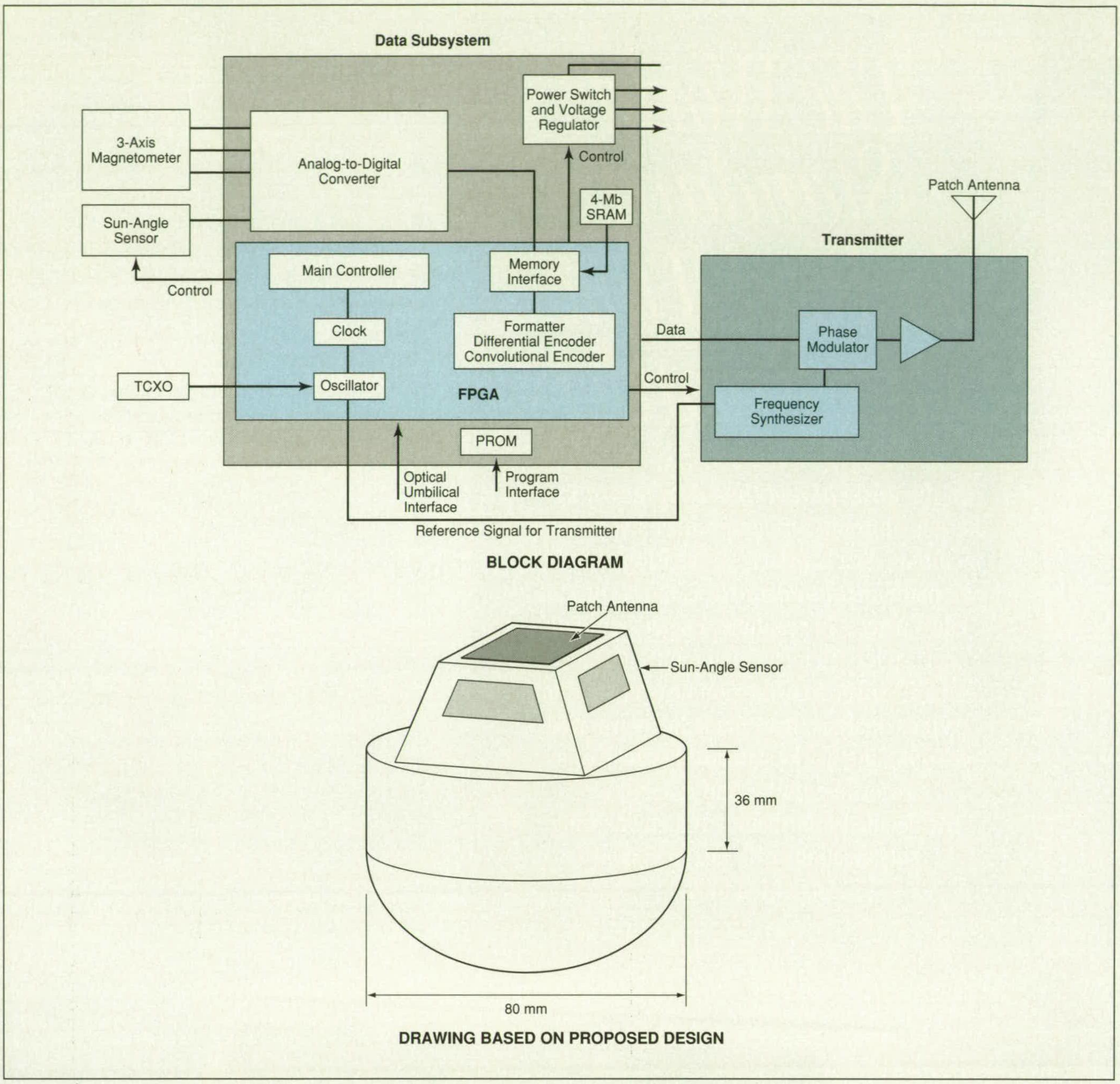
Inexpensive, mass-produced units would be deployed in large numbers.

NASA's Jet Propulsion Laboratory, Pasadena, California

Compact, low-power-consumption magnetic-sensor units called "integrated sensor system" (ISS) units are being developed for detecting buried mines and arsenals without exposing human searchers to unnecessary danger. The fully developed ISS units would be mass produced at relatively low cost, so that they could be deployed in large numbers and regarded as disposable. Many ISS units would be dispersed onto a mine field from a low-flying aircraft. After a specified time, the ISS units would transmit magnetic-field- and attitude-measurement data to the same or different aircraft for processing. Analysis of the data would reveal local deformations of the Earth's magnetic field, indicative of the magnetic dipole moments of mines and other objects.

Each ISS unit (see figure) would contain a miniature three-axis flux-gate magnetometer, a Sun-angle sensor, a data subsystem, a battery power subsystem, a transmitter, and a patch antenna. The ISS unit would be packaged with nonmagnetic components. The entire unit would be designed with great care to ensure that the magnetometer readings would not be corrupted despite the proximity of the magnetometer to the electronic circuitry and packaging.

The three-axis magnetometer chosen for the ISS is one that was recently developed for use in an airborne unit. It includes low-noise ferromagnetic cores with windings for the three axes, plus



This **ISS Unit** is one of many that would be dispersed over the ground to detect magnetic-field anomalies caused by mines.

drive and readout circuits made of commercially available components.

The Sun-angle sensor, designed previously for use on small satellites, is a wide-angle optoelectronic sensor module in a pyramidal housing. The angle of the Sun, relative to the unit, is deduced from differences among the currents generated by four solar photovoltaic cells.

The data subsystem would include a 22-bit analog-to-digital (A/D) converter. The flow of data and the general operation of the rest of the ISS unit would be controlled by a field-programmable gate array (FPGA). A 4-Mb static random-access memory (SRAM) would store data (typically about 7 minutes' worth) until transmission. Data would not be acquired during transmission because operation of the transmitter could corrupt the magnetometer readings.

The battery power subsystem would include six high-capacity $Li/SOCl_2$ cells, plus power-regulation circuitry that is part of the data subsystem. Once activated, the ISS unit would continue to operate until the battery runs down (nearly two hours).

The transmitter would operate at a center frequency of 2,250 MHz. It would contain a frequency synthesizer in the form of a voltage-controlled oscillator locked in phase with a temperature-controlled crystal oscillator (TCXO). The output of the frequency synthesizer would be phase-modulated with the data signal, then amplified, then fed to the patch antenna.

Future refinements of the ISS design would effect increases in magnetic sensitivity, making it possible to detect mines with smaller magnetic moments. Of course, the magnetic-field-based ISS units would not be capable of detecting mines constructed entirely of nonferrous materials. On the other hand, they can be expected to detect a variety of mines of a low-technology type that are built at clandestine factories and have large magnetic moments. As newer mines are made with ever weaker magnetic moments, the basic ISS design could be modified to incorporate electronic chemical sensors to detect explosive vapors.

This work was done by Hamid Javadi of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-20471

Resonant Microstrip Patch Antenna as Ice-Thickness Gauge

Conformally mounted sensors would measure prelaunch ice buildup on space-shuttle external tanks.

Lyndon B. Johnson Space Center, Houston, Texas

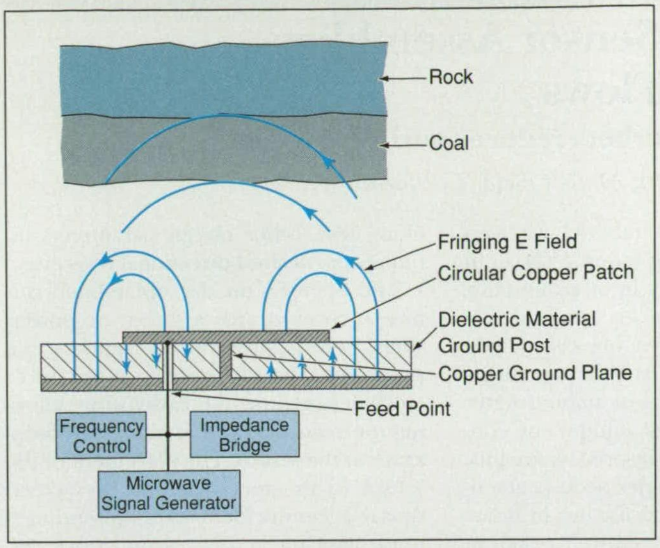
Researchers at Johnson Space Center (JSC) recently demonstrated that the resonant microstrip patch antenna (RMPA), which has been proven in commercial applications, can be applied with equal success to measuring prelaunch ice buildup on the insulated low-temperature external tanks of the space shuttle orbiter. To do this, they explored the following questions: Why is prelaunch ice buildup on the shuttle external tanks measured, how is the ice measured now, how does the RMPA sensor work, and will the performance of this sensor satisfy the Space Shuttle Program launch-commit criteria.

Accurately measuring prelaunch ice buildup on the orbiter external tanks is a programmatic concern. After the tanks are filled, launch countdown continues unless the "acreage ice" builds to more than 1/16 in. (1.6 mm), at which point the applicable launch-commit criterion requires that the launch be delayed. The delay is necessary because, during initial ascent through the atmosphere, an ice layer thicker than 1/16 in. (1.6 mm) could become fragmented, causing damage to orbiter heat-shield tiles and windows. Therefore, the ability to measure the thickness of ice is vital to vehicle performance and safety. At present, ice measurements are performed on the launch pad, by teams of technicians who manually scratch away the ice layer to determine its thickness. However, the large size of external tanks limits accessibility and the number of measurements that can be taken in this way. A sensor that could automatically perform these measurements would increase accessibility and reduce risk.

JSC researchers needed a sensor that could be applied to the Shuttle's external tanks; the RMPA sensor and associated microprocessor-controlled electronic circuitry satisfied their need. But there was a drawback: Inasmuch as active circuits are essential parts of an RMPA sensor, operation of the circuits could, potentially, cause localized heating that could cause inaccurate measurements. Therefore, a multiple-element RMPA that could be integrated into the tank insulation was designed.

An RMPA sensor is driven by a microprocessor-controlled microwave signal generator. It is characterized by, among other things, an electric field (E field) distributed throughout a dielectric material between a circular copper patch and an underlying copper back plane (ground plane) through the dielectric material. The RMPA sensor can be modeled as a high-Q cavity (where "Q" denotes the resonance quality factor) that capitalizes on its resonant sensitivity; this means that it offers a distinct advantage over a nonresonant electromagnetic (EM)-wave sensor.

The high-Q cavity is bounded by the circular copper patch and the ground plane. The E field within the cavity is both excited and sensed by use of a probe perpendicular to the ground plane at the feed point. An example of the E field within the cavity and the associated fringing E fields is illustrated in the figure. The magnetic (H) field, which is not shown in the figure, is orthogonal to the E field. The magnetic field in the vicinity of the edge of the cir-



A **Resonant Microstrip Patch Antenna** is configured for use in sensing nearby material layers. The electric-field lines depicted here approximate those of the transverse magnetic 1,1 (TM11) mode.

cular patch is associated with currents that flow along the patch and ground-plane surfaces, and can be regarded as a diffuse magnetic boundary of the resonant cavity. The fringing E and H fields play an important role in the operation of the RMPA because they constitute the means for coupling between the internal cavity fields and the external fields.

The high-Q RMPA transmits primary electromagnetic fields and senses reflected and scattered electromagnetic fields through alteration of its resonant condition. The RMPA emits a continuous-wave signal that is partly reflected and partly transmitted at interfaces between layers of materials in and near the antenna, including layers of nearby materials (e.g., coal, rock, and/or ice) that one seeks to characterize.

The return signal, which is coupled through the fringing fields, alters the E field at the feed point. The microprocessor-controlled electronic circuitry of the RMPA changes the signal frequency until the measured impedance or admittance is real. The resonant resistance or conductance measured at the feed point can change by a significant amount when the layers of materials change.

The RMPA sensor has been proven useful in several commercial applications; for example, to measure the thickness of ice on a roadway, to measure the thickness of uncut coal in a mine, and as an ore-pass monitor. It should be possible to put the RMPA to good use in measuring ice buildup on the orbiter low-temperature external tanks. The replacement of measurements by technicians with measurements by RMPA sensors would make it possible to measure ice buildup on a greater portion of the tank surface in a timely manner; this would enable launch personnel to satisfy the applicable launch-commit criterion and to reduce the potential danger to the shuttle and its crew.

This work was done by Larry G. Stolarczyk of Raton Technology Research, Inc., for **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Larry Stolarczyk
Raton Technology Research
848 Clayton Highway
Raton, NM 87740

Refer to MSC-22766, volume and number of this NASA Tech Briefs *issue, and the page number.*

Acoustical-Sensor Assemblies for Use in Flows

Screens and absorbers reduce spurious signals.

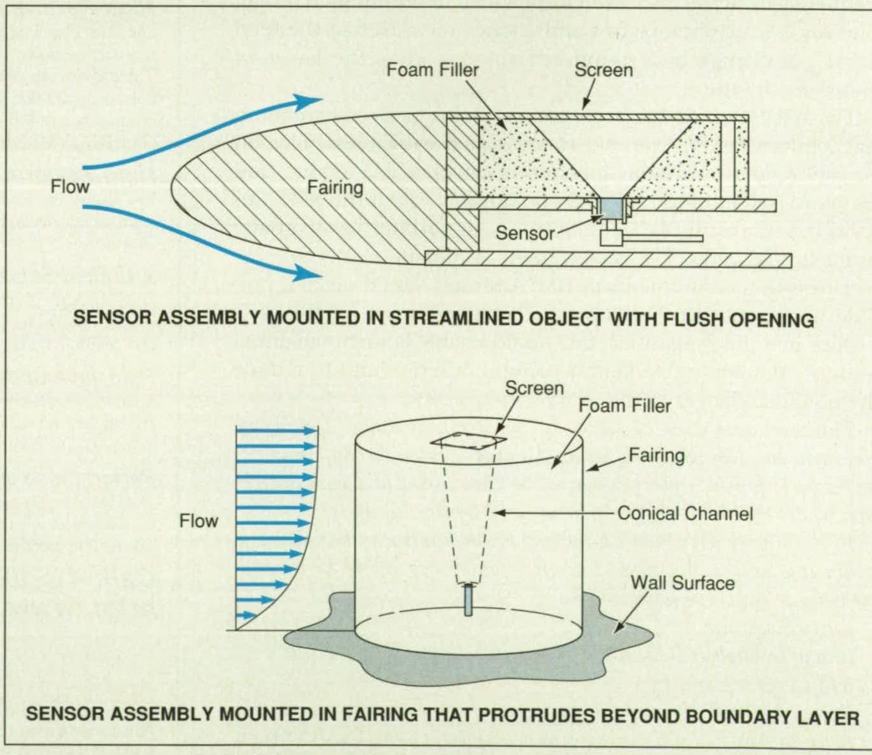
Ames Research Center, Moffett Field, California

Improved sensor assemblies have been invented for measuring acoustic signals in gases or liquids flowing in or around any of a variety of moving or stationary objects. Examples of such objects include land vehicles, aircraft, submarines, structures exposed to winds or natural water streams, and industrial equipment containing or surrounded by process streams. In comparison with older acoustical-sensor assemblies designed for use in flows, these assemblies offer reduced response to noise generated by flows at and near sensor-assembly surfaces and increased protection for fragile acoustical transducers. These assemblies can be made to discriminate against sounds coming from outside preferred ranges of directions. They can also be mounted flush with surfaces of objects to minimize flow-induced noise and drag.

The figure illustrates two assemblies within the scope of the invention. In each case, the sensor is a microphone or other dynamic-pressure transducer. Each sensor is mounted in a cavity, wherein it is recessed from a streamlined surface. The cavity is lined with a sound-absorbing foam filler. A hole in the filler tapers conically from the sensor at its narrow end to an opening on the streamlined surface at its wide end. The cone angle is chosen, along with other design parameters, to obtain the desired directional response.

The opening on the streamlined surface is covered with a screen or porous sheet, which prevents or reduces the propagation of surface-flow disturbances (turbulence) into the cavity while allowing the acoustic waves of interest to propagate to the sensor. The placement of the sensor in the recess behind the screen thus reduces the intensity of flow-induced noise arriving at the sensor. Moreover, spurious acoustic disturbances arriving from immediately upstream or downstream of the opening can be rejected by reflection from the shear layer in the flow adjacent to the screen. Because the fluid in the cavity is still or nearly still, relative to the fluid outside the cavity, the sensor is protected against damage by the flow. The screen also protects the sensor against impacts of particles entrained in the flow.

The sensor assembly shown in the upper part of the figure is mounted inside a streamlined body with a rounded fairing on its upstream end, for measuring sounds arriving at the surface of the body. The sensor assembly shown in the lower part of the figure is mounted on the wall of an object; this sensor assembly includes its own fairing, which protrudes into the



Sensors Are Mounted Behind Screens at the apices of conical holes in sound-absorbing foam fillers.

flow beyond the wall boundary layer or free shear layer, for measuring sounds free of interference from turbulence in this layer.

This work was done by Fredric Schmitz, Sandy Liu, Stephen Jaeger, and W. Clifton Horne of **Ames Research Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

This invention has been patented by NASA (U.S. Patent No. 5,684,756). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center; (650) 604-5104. Refer to ARC-12099.

Biotelemetry Using Implanted Unit To Monitor Preterm Labor

Pressure changes are telemetered to the outside and analyzed to detect intrauterine contractions.

Ames Research Center, Moffett Field, California

A biotelemetric system for monitoring key physiological parameters of a fetus and its uterine environment is undergoing development. The main purpose of the monitoring is to detect preterm labor in order to enable timely treatment. At the present stage of development, the system monitors pressure changes and temperature. The pressure changes serve as direct indications of intrauterine contractions that could be associated with the onset of preterm labor. Future versions of the system are expected to monitor additional parameters, including pH and the heart rate of the fetus.

The system (see Figure 1) includes a transmitting unit that contains a thermistor (the temperature sensor) and a piezoresistive transducer (the pressure sensor), a receiver, data-acquisition subsystem, and a digital signal-processing subsystem. The fully developed transmitting unit is projected to be small enough that it could be introduced into the uterine cavity through a 10-mm trocar during endoscopic fetal surgery; the surgical procedure for implanting this transmitter would be less invasive than are the hysterotomies performed to implant the transmitting units of telemetric systems developed previously for the same purpose.

The transmitter generates a pulsed signal at a carrier frequency between 174 and 214 MHz. The temperature and pressure information are conveyed by pulse-interval modulation (PIM): Pulses are transmitted in pairs at a pulse-pair-repetition frequency of about 1 to 2 Hz. The interval between the two pulses in each pair is proportional to the sensed pressure, while the interval between pairs is proportional to the departure of the sensed temperature from a predetermined nominal value. The low data rate is sufficient for monitoring intrauterine contractions, which typically occur over several minutes. The transmission range is 3 to 10 ft (1 to 3 m), depending on the position of the transmitter in the body.

Transmitter power is supplied by two silver oxide batteries; at an average power consumption <40 μW, the operational lifetime ranges from 4 to 6 months. The fully developed transmitting unit would be electronically identi-

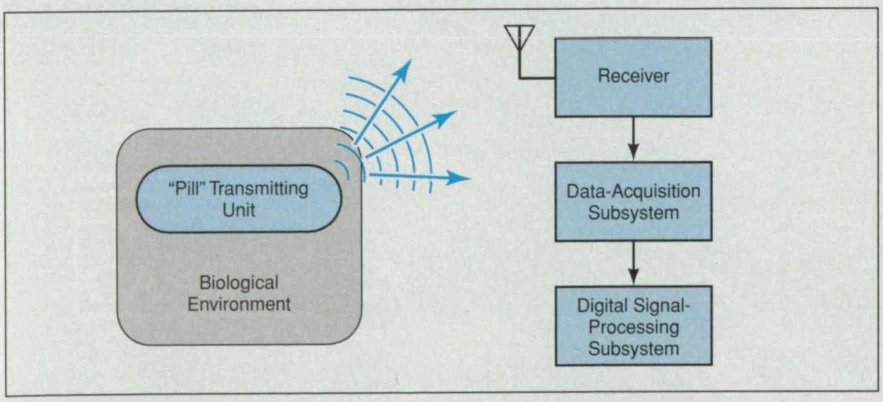


Figure 1. A **Transmitting Unit in a Uterus** monitors physiological parameters and transmits its reading to external equipment. The fully developed transmitting unit, resembling a large pill, would be small enough to be implantable by minimally invasive surgery.

cal to a larger prototype that has already been constructed (see Figure 2), but would be miniaturized by following the chip-on-board approach, in which unpackaged integrated-circuit chips are flip-chip bonded directly onto a printed-circuit board along with other components. The transmitter is encapsulated in biocompatible silicone rubber.

The receiver converts the PIM radio-frequency signal into a digital pulse stream, which is then decoded to obtain voltages proportional to the temperature and pressure readings. These voltages are digitized in the data-acquisition subsystem, which is a Personal Computer Memory Card Association (PCMIA) circuit card in a laptop computer. The digital data are then processed in the digital signal-processing system, which is the remainder of the laptop computer.

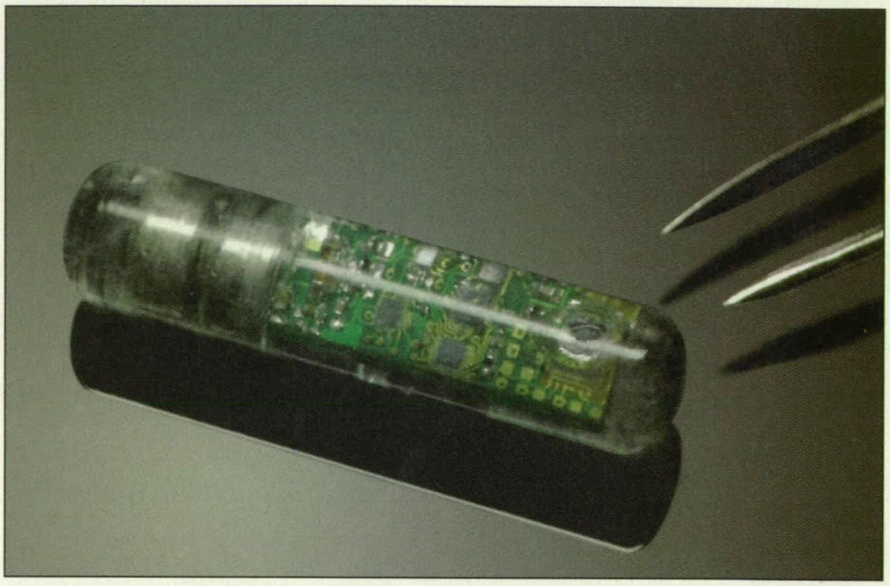


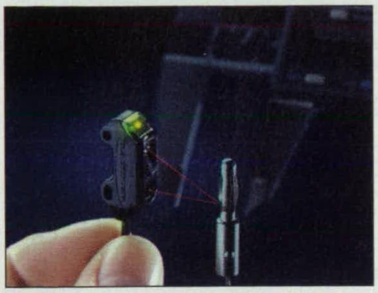
Figure 2. A **Prototype Transmitting Unit** would be miniaturized and encapsulated in biocompatible silicone rubber.

The processing is done by a LabVIEW® program that displays and stores the pressure and temperature data as functions of time, performs peak detection, and determines the frequency of contractions. The program integrates the pressure over time to obtain an index of the amount of preterm labor. A unique feature of the program is the application of statistical and frequency-analysis functions to the pressure data to help a pediatric surgeon detect preterm labor. Among other things, the program displays the frequency spectrum of intrauterine contractions. Another unique feature is a contraction-detecting algorithm.

This work was done by John W. Hines of **Ames Research Center** *and Christopher J. Somps, Robert D. Ricks, and Carsten W. Mundt of Sverdrup Technology, Inc. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center; (650) 604-5104. Refer to ARC-14280.

Special Coverage: Sensors



The VS1 Series self-contained **photoelectric sensor** from Banner Engineering Corp., Minneapolis, MN, is a convergent mode sensor with built-in amplifier that can switch loads up to 50 milliamps. The tiny sensing system is designed for space-restricted areas, such as inside machinery. It operates on 12 to 24V dc and uses a visible red sensing beam in the convergent sensing mode to form a visible spot at either a 10-mm or 20-mm focus.

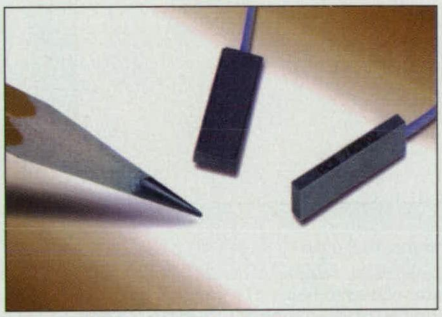
The sensor provides repeatability of 250 microseconds, with output response time of 1 millisecond. Green and yellow LED indicators provide operating status information. Users have a choice of light operate (N.O.) or dark operate (N.C.) models. The sensor operates in temperatures of -20°C to +55°C, and has a black ABS/polycarbonate housing with an acrylic lens.

For More Information Circle No. 711

Baumer Electric, Southington, CT, has introduced a family of **ultrasonic position sensors** with analog output and tech mode. The sensors offer single, one-button programming and require no special tools for set-up. The teach function allows the user to select both limits of the sensing range and the steepness of the analog output. The output function is invertible, which allows the user to select a rising or falling output slope for each application.

All adjustments are made using the teach-in button, and settings can be monitored using the multi-colored LED indicator. Operating range is 100 to 700 mm, and the analog output supplies 0 to 10 volts. Set-up configuration is saved on an internal EEPROM. Applications include breakage control, monitoring roll diameters, and measuring applications.

For More Information Circle No. 707



The Model 740B02 **dynamic strain sensor** from PCB Piezotronics, Depew, NY, features ICP® sensor microelectronic circuitry and a quartz sensing element for measuring small dynamic strain on top of large static loads. The high-resolution sensor also can be used to detect wave propagation for material velocity characterization.

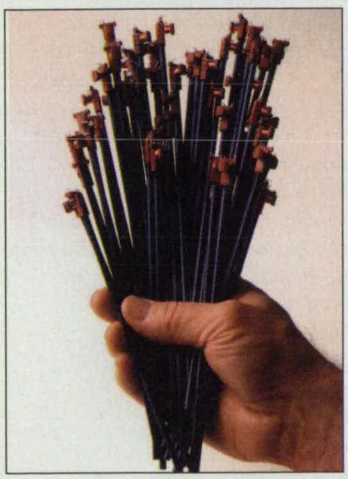
The sensor is designed for use in active vibration control, noise-path analysis, modal testing, and for use on aircraft, composite materials, smart structures, and vibrating machinery. It has sensitivity of 50 mV/με and an amplitude range of ±100 με peak. Housed in titanium, the sensor has a low profile and possesses a 10-foot integral cable, terminating in a 10-32 connector.

For More Information Circle No. 709

Patriot Sensors & Controls Corp., Simi Valley, CA, offers the SP101 **pressure transducer**, which features a flush-mount design and high frequency response with pressure ranges from 15 to 5,000 psi. Units are interchangeable without system calibration, making them suitable for applications with small envelope restrictions or where non-clogging installation is required. Capabilities include a 200% overpressure and up to a 1000% burst pressure.

The transducer can be mounted onto walls of machined or plastic housings, in a reservoir, or against flexible tubing. The design flexibility allows pressure output readings for monitoring pressure in small vessels, medical equipment, automated manufacturing equipment, pipes, or pumps. The unit has a corrosion-resistant stainless steel diaphragm.

For More Information Circle No. 710



MTS Corp., Sensors Div., Cary, NC, offers Temposonics® Auto-SE **position sensors** for product designers in the medical, automotive, aeronautic, and consumer products fields. The sensors eliminate degradation under regular shock, vibration, and high-cycle wear. They are non-contact and based on the company's magnetostrictive technology.

The magnetostrictive linear position sensors are protected from the elements and have a long life expectancy with virtually no maintenance requirements. The sensors' design flexibility allows them to be used in a variety of applications by product designers, engineers, and R&D professionals.

For More Information Circle No. 708

SIE Sensors, Toledo, OH, has introduced a series of self-contained, compact, capacitive **proximity sensors** available in 6.5-mm, M8, 10-mm, M12 housings. The VDC sensors feature outputs in PNP or NPN, normally open or normally closed. Sensing distances range from 1.5 to 8 mm, and are adjustable with the potentiometer and complimented with an LED status indicator.

Each unit is available with 2M cable or quick-disconnect. The sensors are IP67 rated, CE approved, protected from short-circuiting and overloads, and have a temperature range from -30°C to +70°C. They are available with a choice of metal, stainless steel, PVC, or PTFE housings. They can detect materials such as plastic, glass, ceramics, metal, liquids, and wood in true flush mountings.

For More Information Circle No. 706

$LaNi_{5-x}M_x$ Alloys for Ni/Metal Hydride Electrochemical Cells

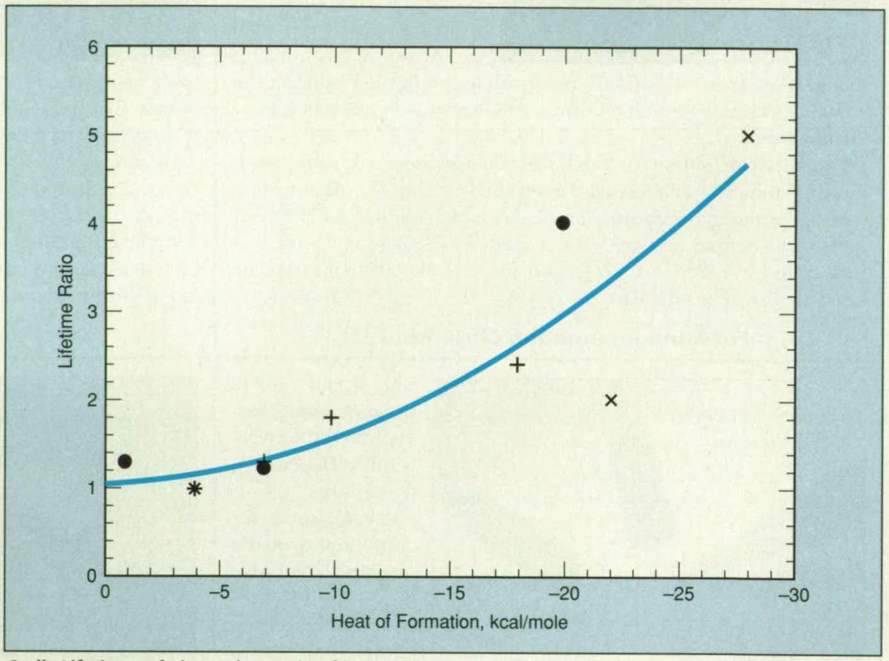
A systematic approach to extension of cycle lives has emerged from recent studies.

NASA's Jet Propulsion Laboratory, Pasadena, California

Studies of physical and chemical effects in the hydride-forming electrodes of rechargeable nickel/metal hydride electrochemical cells have yielded results that now guide efforts to formulate improved electrode alloys to extend the cycle lives of the cells. These efforts involve finding appropriate ternary solutes and amounts of those solutes to alloy with the original hydride-forming binary alloy $LaNi_5$ to form alloys of general composition $LaNi_{5-x}M_x$. Here, M denotes any suitable element or alloy that forms a strong bond with lanthanum, as explained below.

Findings consistent with this approach were reported in two previous articles in *NASA Tech Briefs*: "$LaNi_{5-x}Sn_x$ Electrodes for Ni/MH Electrochemical Cells" (NPO-19805), Vol. 22, No. 8 (August 1998), page 60 and "$LaNi_{5-x}Ge_x$ Electrodes for Ni/MH Electrochemical Cells" (NPO-19962), Vol. 22, No. 8 (August 1990), page 61. At the time of reporting the information for those articles, there was no explanation of the basic physical and chemical mechanisms for the degradation of cycle lives of $LiNi_5$ electrodes and for the improvements afforded by partial substitution of Sn or Ge for Ni. The basic mechanisms are still not well understood, but the following understanding has emerged from the research performed thus far:

Hydrides of $LaNi_5$ are thermodynamically unstable against disproportionation reactions in which they decompose into Ni plus LaH_2 or $La(OH)_3$. In addition, upon absorption of hydrogen, $LaNi_5$ can expand by as much as 24 volume percent; the combination of large expansion during absorption and the corresponding large contraction during subsequent desorption of hydrogen induces structural defects and reductions in particle sizes, with a consequent increase in the diffusion of metal atoms in the $LaNi_5$ crystalline lattice. This increase in diffusion increases the La content at the surface, where the La is readily oxidized to form a thick hydroxide layer in one of the disproportionation reactions. The present approach involving formulation of $LaNi_{5-x}M_x$ is based on suppressing diffusion of La and thereby preventing disproportionation of $LaNi_5$.



Cyclic Lifetimes of electrodes made of $LaNi_{5-x}M_x$ are related to heats of formation of M with La. The lifetime ratio for a given M is defined as (the number of charge-discharge cycles to half of initial charge capacity for an electrode made of $LaNi_{5-x}M_x$) ÷ (the corresponding number of cycles an electrode made of $LaNi_5$).

More specifically, the approach is to seek compositions and crystalline structures to immobilize lanthanum atoms in the Haucke-phase metal hydrides. The most promising ternary solutes for this purpose should be elements that form the strongest chemical bonds with lanthanum— stronger than the bonds between nickel and lanthanum. The solute atoms would be positioned on the nickel planes of the Haucke phase, so that they would be close to lanthanum neighbors. Strong bonds to neighboring atoms would suppress the formation of crystalline-lattice defects as well as movements of lanthanum atoms.

Preliminary support for this approach has been found through an analysis of cyclic lifetimes for various solutes as reported in the literature; the analysis reveals a close relationship between cyclic lifetime and the heat of formation of the solute with lanthanum (see figure). The finding of this relationship motivated the hypothesis that the rates disproportionation and/or degradation could be reduced by adding solutes that bond strongly with lanthanum. Among the solutes that exhibit high heats of formation with lanthanum are germanium and tin (mentioned in the cited prior articles), plus indium.

This work was done by Ratnakumar Bugga, Robert Bowman, Adrian Hightower, Charles Witham, and Brent Fultz of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-20107, volume and number of this NASA Tech Briefs *issue, and the page number.*

Finite-Width Coplanar-Waveguide Patch Antenna

Developmental phased-array antennas would incorporate antenna elements like this one.

John H. Glenn Research Center, Cleveland, Ohio

The upper part of Figure 1 illustrates an antenna derived by widening the middle strip conductor of a finite-width coplanar waveguide (FCPW) to form a rectangular patch. An FCPW offers all the advantages of a conventional coplanar waveguide, along with the additional advantage that its finite-width ground planes suppress the propagation of spurious substrate electromagnetic modes that would otherwise degrade the electrical performance of an array of patch antenna elements.

The lowest order of resonance of an FCPW patch antenna occurs at a frequency for which the guide wavelength, $\lambda_{g(slot)}$, equals the sum of mean lengths of slots from point a to point i. At resonance, the electric-field lines are oriented as shown by the curved arrows, and the antenna radiates with a polarization parallel to sides c–d and f–g.

An experimental FCPW antenna element like that of Figure 1 was fabricated by use of gold paste and screen printing on ceramic substrates. The substrate material had a relative permittivity of 5.9, making it possible to reduce patch dimensions significantly to make an array of such elements more compact. Dimensions included D = 0.01125 in. (0.286 mm), S = 0.012 in. (0.305 mm), W = 0.004 in. (0.102 mm), and G = 0.024 in. (0.700 mm). The input impedance of the antenna was measured by use of through-reflect-line on-wafer calibration standards, a pair of microwave probes, an automatic network analyzer, and de-embedding software from the National Institute of Standards and Technology; these measurements revealed that the antenna resonated at frequency of 19.95 GHz with a de-embedded input impedance of 534 Ω at plane P–Q.

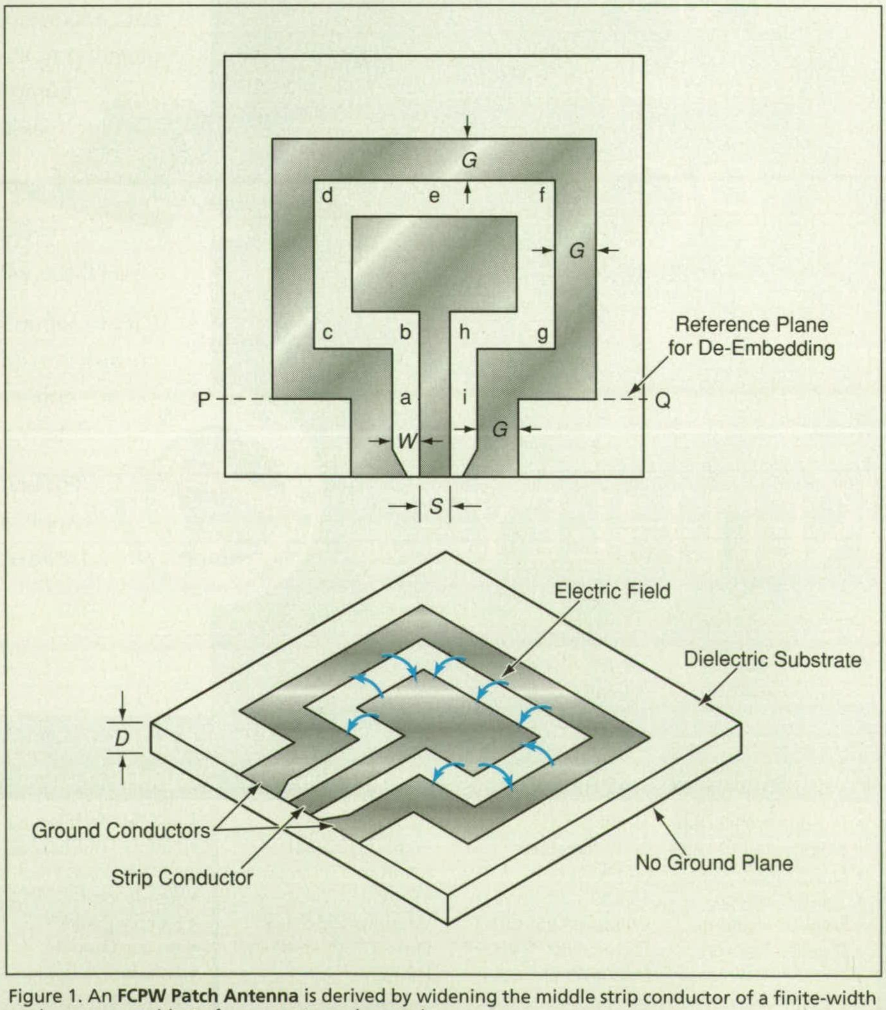


Figure 1. An **FCPW Patch Antenna** is derived by widening the middle strip conductor of a finite-width coplanar waveguide to form a rectangular patch.

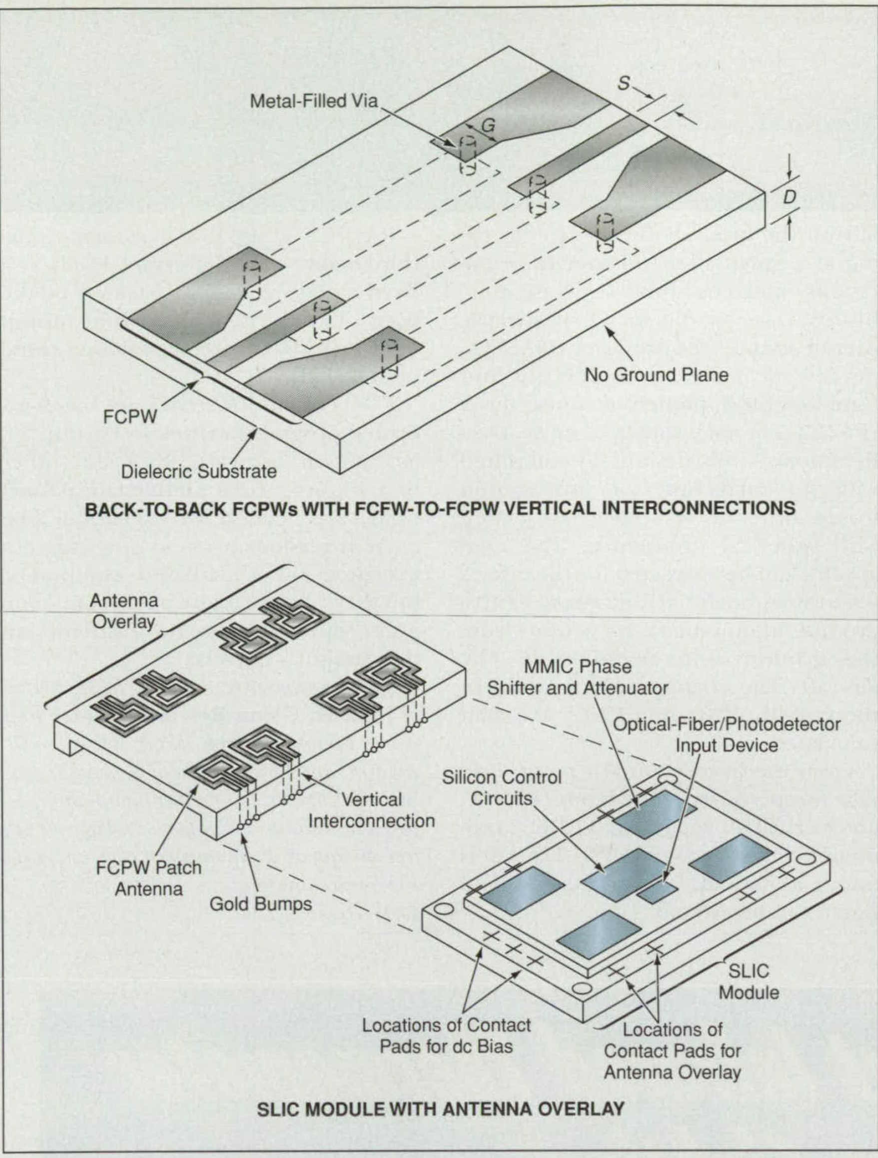


Figure 2. **FCPWs and FCPW Patch Antennas** are elements of developmental modules that will eventually be used to make compact phased-array antennas.

The upper part of Figure 2 illustrates two back-to-back FCPWs on the top side of a dielectric substrate, a connecting FCPW on the bottom side of the substrate, and FCPW-to-FCPW vertical interconnections (vias). An experimental unit having this configuration was made of substrate material and conductor strips with dimensions *D, S, W*, and *G* as described above, and with vias of ≈0.01 in. (≈0.25 mm) diameter.

The lower part of Figure 2 shows a system-level integrated circuit (SLIC) module that was undergoing development at the time of reporting the information for this article. The completed module would contain all the circuitry of an eight-element phased-array antenna. The module would contain four dual-channel monolithic microwave integrated circuits (MMICs) and supporting circuitry. Each of the dual channels would contain a three-bit phase shifter, an analog attenuator, and amplitude-calibration and -control elements. A photonic link would bring the radio-frequency signals and digital control signals into the module. Another photonic link would return information on the status of the module to an external controller.

This work was done by Richard Q. Lee and Kurt A. Shalkauser of **Glenn Research Center;** *Jonathan Owens, James Demarco, Joan Leen, and Dana Sturzebecher of PSD, Army Research Laboratory, AMSRL-PS-E; and Rainee N. Simons of NYMA, Inc. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7–3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16666.

Software

Updated Software for Predicting Noise From Aircraft

The FOOTPR and RADIUS computer programs implement state-of-the-art mathematical models for predicting levels of noise generated by existing or proposed aircraft. These programs can be used to calculate Federal Aviation Administration (FAA) noise-certification levels, airport-vicinity noise footprints, and levels of noise generated during climb and en route. FOOTPR and RADIUS originated in research at Lewis (now John H. Glenn) Research Center in the year 1981. Since that time, seven jet-noise models, four fan-noise models, a fan-noise-suppression model, and second core and turbine-noise models have been added to these codes, and a ground-reflection model already in the codes has been enhanced.

FOOTPR computes histories of noise at various observer stations (usually on the ground) for an aircraft flying at a specified set of speeds, orientations, and coordinates. These time histories are in the forms of spectra, overall sound-pressure level (OASPL), perceived noise level (PNL), and tone-weighted perceived noise level (PNLT). For each source of noise, free-field noise levels are initially computed with no correction for propagation losses other than those associated with spherical divergence. The total spectra can be corrected for the effects of atmospheric attenuation, extra ground attenuation, reflection from the ground, and shielding by the aircraft. The corresponding values of the OASPL, PNL, and PNLT are then calculated.

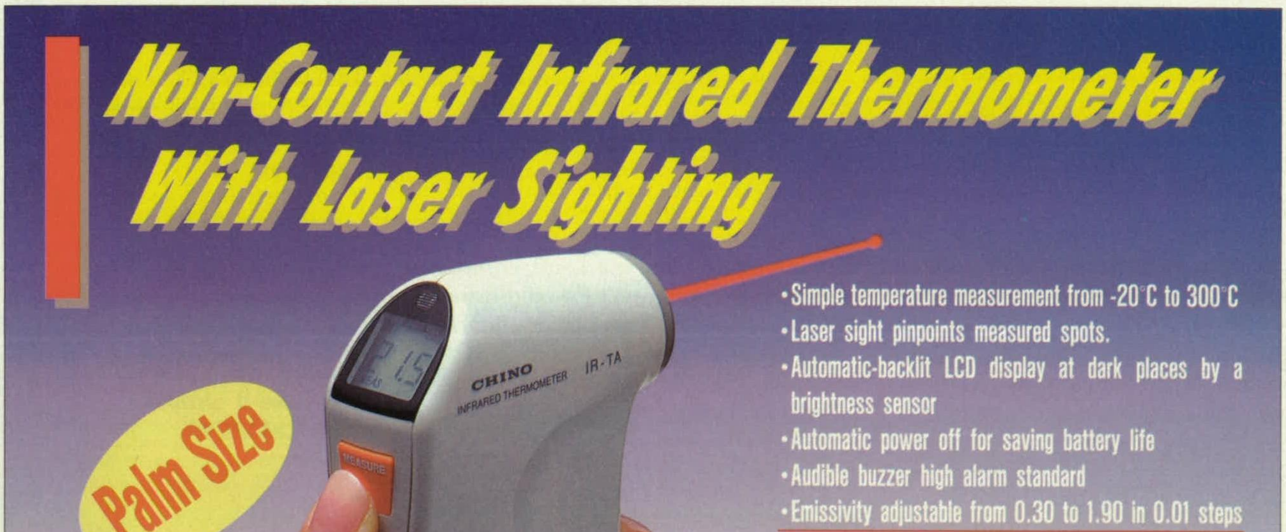
From the history at each point, true effective perceived noise levels (EPNLs) are calculated. Values of EPNL, maximum PNL, or maximum PNLT are thus found, as desired, for a grid of specified points on the ground.

RADIUS computes customary one-third-octave sound-pressure levels at a fixed radius at angles specified by the user. The noise-source subroutines used in RADIUS are the same as those in FOOTPR.

FOOTPR and RADIUS are batch-executed programs written in Fortran 77. No system software libraries (other than those for basic mathematical functions) are needed for execution. The current versions of these programs are executed on Unix-based computers, but they can be run on almost any computer/operating system combination that supports Fortran.

This program was written by Jeffrey Berton of **John H. Glenn Research Center** *and Karen Kontos, Robert E. Kraft, Bangalore Janardan, and Philip Gliebe of General Electric Aircraft Engines. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

LEW-16576



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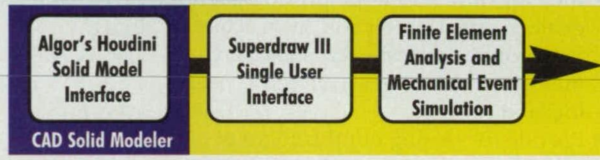

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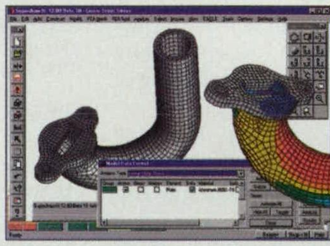

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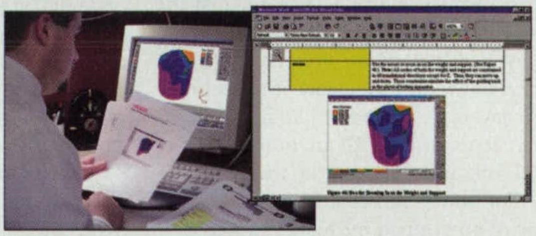

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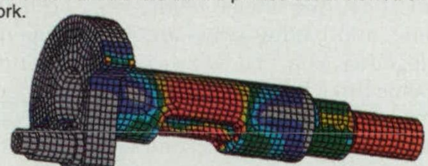

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For More Information Circle No. 519

Materials

Durable Advanced Flexible Reusable Surface Insulation

Blankets covered with impermeable foils are sealed loosely at their edges.

Ames Research Center, Moffett Field, California

Continuing efforts to develop lightweight, flexible thermal-insulation blankets that withstand high temperatures have led to design and fabrication concepts that effect the following improvements:

- Increase durability while providing adequate thermal protection to structures that would otherwise be subjected to multiple cycles of aeroconvective heating; and
- Provide for closing out the edges of insulating blankets in such a way as to minimize intrusion of water, minimize leakage of heat, provide smooth aerodynamic surfaces at joints between adjacent blankets, and accommodate thermal expansion without buckling of outer blanket surfaces.

Blankets that incorporate these improvements are denoted collectively as "durable advanced flexible reusable surface insulation," and are the latest in a series of similarly named blankets made largely of ceramic fibers.

As shown in Figure 1, a blanket of the present type includes (1) a bulk insulating layer of fibrous ceramic batting sandwiched between inner and outer ceramic fabric layers, (2) a screenlike metal fabric woven from wire, (3) an outer layer of metal foil, and (4) ceramic thread stitching. The metal fabric and foil layers are made of one or two refractory metal(s) — typically, nickel alloy(s).

In fabrication, the metal fabric, ceramic fabric, and batting layers are first stitched together as a first subassembly, using ceramic threads in a lock-stitch pattern. After stitching, the outer ceramic fabric layer is heat-cleaned. A second subassembly is then formed by attaching the metallic fabric layer to the first subassembly, and, in particular, to the ceramic fabric layer by stitching along lines that lie between the first-subassembly stitch lines. Portions of the outer ceramic and metal fabric layers protrude beyond the edges of the stitched area; these portions are stitched together with ceramic thread to form closeout extensions.

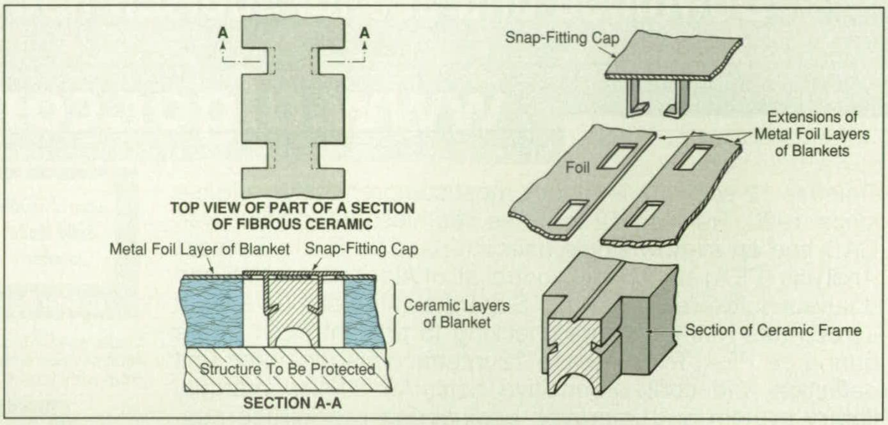

Figure 2. **Foil Extensions at the Edges of Two Adjacent Blankets** are held on the frame and sealed by the snap-fitting cap.

The metal-foil layer is then brazed to the metal fabric, thereby providing a relatively impermeable outer layer that helps to protect the ceramic layers against intrusion by water. Unlike in another design, there is no need to braze the metal foil to the ceramic fabric; therefore, a conventional brazing alloy can be used. (Conventional brazing alloys tend not to wet ceramic surfaces.)

After brazing, the blanket is closed out by any of three different methods, only one of which can be described in the space available for this article: A frame of fibrous refractory insulating material is placed around the periphery of the blanket. The frame can be made in sections [typically about 6 in. (≈15 cm) long] and is designed to permit flexing of the blanket on the perimeter without creating any gaps. The frame sections are attached mechanically to the surface of the structure to be protected.

Figure 2 depicts part of a frame that abuts two adjacent blanket sections. The metal-foil layer of each blanket extends onto the outer (top in the figure) surface of the frame. Pairs of rectangular opposed recesses are machined into each frame section, and rectangular openings are made in the metal-foil extensions at the locations of the recesses in the frame. A snap-fitting cover includes pairs of legs that extend through the openings into the recesses. The legs engage the recessed surfaces so as to secure the cover over the edge portions of the foil layers. The blankets are thus sealed on the surface by snapping in the cover.

This work was done by Daniel Rasky, Demetrius A. Kourtides, Daniel L. Dittman, Marc D. Rezin, Clement Hiel, and Wilbur C. Vallotton of **Ames Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at*** ***www.nasatech.com*** *under the Materials category.*

This invention has been patented by NASA (U.S. Patent No. 5,811,168). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center; (415) 604-5104. Refer to ARC-12081.

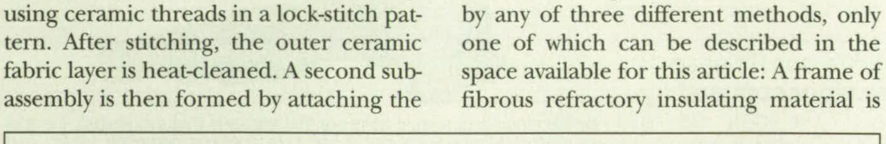

Figure 1. **This Blanket Differs From Other Insulating Blankets** in several respects, including notably the method of attachment of the outer metal foil.

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Mechanics

Eclipse Aerotow Dynamics Experiment

Flight tests have been successful.

Dryden Flight Research Center, Edwards, California

NASA Dryden Flight Research Center is supporting a Phase II Small Business Innovation Research (SBIR) contract between the U.S. Air Force Research Labs and Kelly Space & Technology (KST). KST's innovation is to use an aerotowed reusable launch vehicle to put small satellites into low orbits around the Earth. In support of this idea, the SBIR is to demonstrate aerotow with representative aircraft; namely, a C-141A as the towing airplane and a QF-106A (a modified F-106) as the towed airplane. NASA Dryden has developed a computational simulation of the dynamics of the tow rope and towed airplane, conducted dynamic-stability studies, developed test plans, and completed successful ground, taxi, and flight tests.

Towing a launch vehicle to altitude should make it possible increase the payload and decrease the cost of the launch. No previous aerotow experiments produced tow-dynamics data of any consequence. Dryden's expertise in conducting unusual flight tests was needed to perform simulations of the dynamics (see Figure 1), determine a safe flight-test approach, and conduct the aerotow flight tests.

Dryden provided support for the modifications that were made in converting the F-106 into the towed experimental airplane, and for its operation and maintenance. Dryden also provided research instrumentation, the test range, flight-safety, operations, research pilots, and research engineering analysis of the aerotow system. The Air Force Flight Test Center also supported this project by providing the C-141A airplane and flight crew.

Tests of the entire tow system (see Figure 2) have been completed. These included high-speed taxi (through rotation of the QF-106A airplane) and successful flight tests.

The results of the tests showed that, among other things, the tow rope is not a straight line as previously assumed. The rope exhibits considerable sail from the airflow. Observed stability boundaries do not match those predicted from the simulations; with a differential altitude of approximately 200 ft (60 m) between the aircraft, the tow-rope tensions were sta-

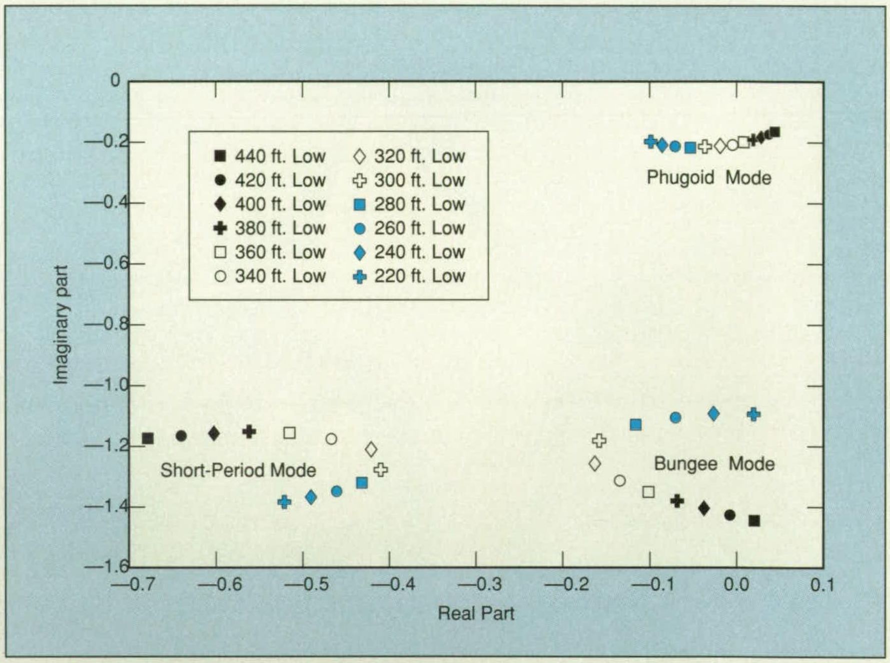

Figure 1. **Eigenvalues of Oscillations of the Tow System** in short-period, phugoid, and "bungee" (simple longitudinal) modes were identified, and a flight envelope for stable towing of the QF-106A behind the C-141A was predicted on the basis of computational simulations of the dynamics.

Figure 2. The **C-141A Airplane Towed the QF-106A Airplane** in flight tests. The airplanes were connected by a tow rope 1,000 ft (305 m) long.

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ble. The rope sail also alters the trim of the aircraft relative to the predictions from the simulations; the angle at the point where the rope meets the QF-106A was found to be more acute than it was predicted to be, making it necessary to use more elevon deflection. Analysis was continuing at the time of reporting the information for this article.

This work was done by Al Bowers and Jim Murray of **Dryden Flight Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*
DRC-98-79

Direct Thrust-Measurement Technique Applied to an F-15 Airplane

Preliminary results show that thrust can be measured accurately by use of strain gauges.

Dryden Flight Research Center, Edwards, California

Direct measurement of aircraft-engine thrust by use of strain gauges offers several advantages over traditional model-based methods of calculating thrust, provided that care is taken during the installation and calibration of strain gauges, and provided further that secondary load paths are understood. Advantages of the strain-gauge-based thrust-measurement method depend upon the specific engine/airframe interface, but can include the following:

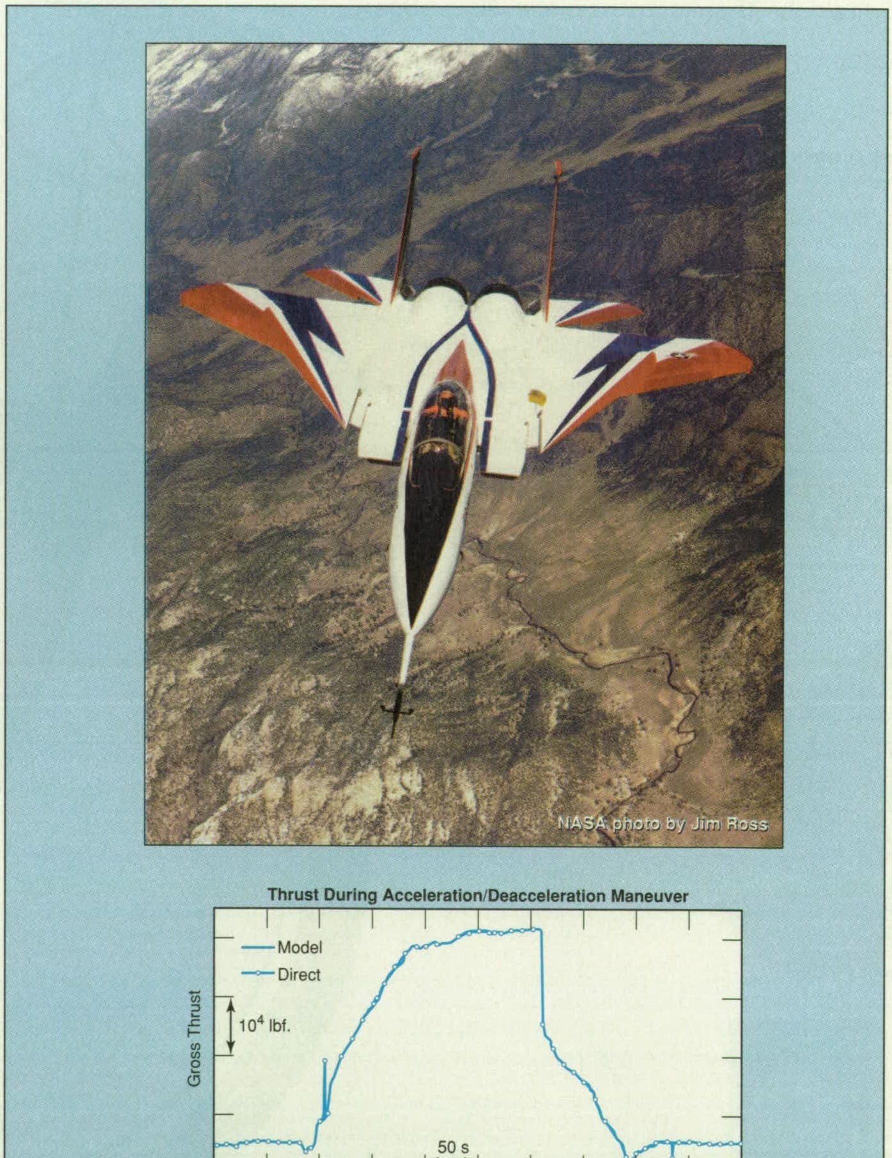
- Simplification of the sensor installation, relative to the sensor suite that would be needed to support model-based calculations;
- Immunity (unlike in model-based methods) to drift and to the associated loss of accuracy as the engine deteriorates over time; and
- Excellent dynamic response.

Flight tests were performed to assess the suitability of the strain-gauge-based thrust-measurement method for application to the full flight envelope and power range of the F-15 airplane powered by F100-PW-229 engines. Other objectives of the flight tests were to determine whether unmeasurable secondary load paths affect the accuracy of this method significantly and to compare direct measurements against proven model-based thrust calculations.

Preliminary results from the flight tests showed that by properly accounting for secondary forces, and through the use of output data from a digital electronic engine-control system, excellent gross thrust-data accuracy was obtained during a subsonic-to-supersonic acceleration maneuver (see figure). Preliminary assessment of measurements throughout the remainder of the flight envelope show similar encouraging results.

At the time of reporting the information for this article, an in-depth analysis of the results from full-flight-envelope tests was planned for the near future, and the results were presented at the 1998 Joint Propulsion Conference. A description of the direct thrust sensor system, along with installation and calibration issues, were to be included in the presentation.

This work was done by Tim Conners and Robert Sims of **Dryden Flight Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*
DRC-98-81



An **F-15 Airplane** at an altitude of 30,000 ft (9.1 km) was made to accelerate from mach 0.9 to mach 2.0, then to decelerate from mach 2.0 to mach 0.9 in a flight test of the strain-gauge-based thrust-measurement method.

Machinery/Automation

Experiment on Quasi-Tailless Flight of an X-31A Airplane

Lessons learned will be applied in future development of thrust vectoring.

Dryden Flight Research Center, Edwards, California

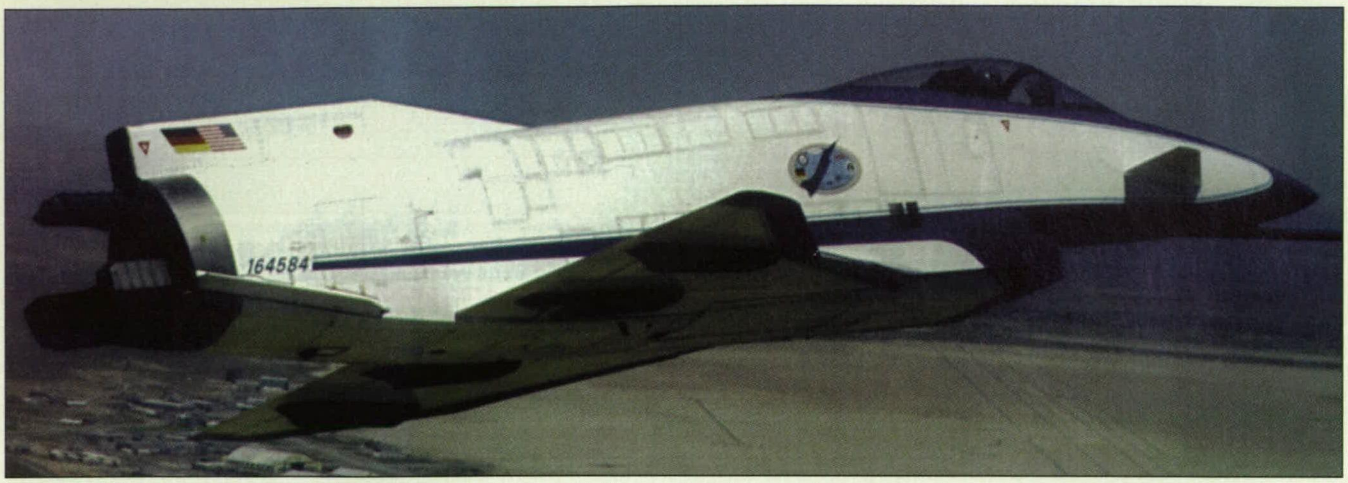
An experiment consisting of flight tests on the X-31A airplane (see figure) has demonstrated the ability to use thrust vectoring to replace the functions of stabilization and turn coordination usually required of a rudder and vertical tail. Comments by the pilot indicated no difference in handling qualities for the majority of the tests flown. The experiment showed that the greatest demand was placed on the thrust-vectoring system at low thrust settings and high roll accelerations. It was demonstrated that a higher level of interaction between the engine and flight-control system will be needed for future reduced-tail or tailless aircraft with thrust-vector control. This experiment helped to introduce thrust vectoring as a new design dimension for future aircraft.

The quasi-tailless concept involves the use of in-flight simulation to assess the effect of partial to total removal of the vertical tail; in implementing this concept in the experiment, the rudder control surface was used to cancel the stabilizing effects of the vertical tail. Yaw-thrust-vector deflections were used to restabilize and control the aircraft. The quasi-tailless mode was flown supersonically with gentle maneuvering. Precise approaches and ground attack profiles were flown subsonically with more aggressive maneuvering.

The supersonic quasi-tailless test showed that maneuvers typically required of transport aircraft could be controlled by thrust vectoring for fairly high levels of instability. A tail-reduction setting of 70 percent was used during part of the experiment and was found to be equivalent to an instability-amplitude-doubling time of approximately 170 ms. The fidelity of the sideslip feedback measurement was found to be a critical factor in determining the amount of destabilization achieved by the quasi-tailless system. The sideslip feedback path included an equivalent delay of approximately 67 ms from complementary filtering of flight-test-boom and inertial parameters, and a deadband caused by misaligned dual redundant sideslip vanes. These factors both influenced the level of destabilization achieved in flight.

To accomplish the objectives of the subsonic tests, it was necessary to maneuver the airplane more aggressively. The precise-approach tests provided a first look at the use of thrust vectoring as a primary means of control at low power settings. The flying qualities were found to be independent of tail-reduction setting up to a setting of 50 percent (an instability-amplitude-doubling time of about 0.92 s). High throttle activity coupled with a lag on the thrust-estimation algorithm resulted in errors in the thrust-control loop gain as high as 4 dB. Because of the high loop-gain margin of the X-31A, these errors did not produce any noticeable stability problems. The tests showed that an accurate and redundant onboard thrust-estimation algorithm is necessary in an integrated propulsion/flight-control system. Either the design of such a system should provide for better estimation of thrust changes resulting from rapid throttle movements, or else a high stability margin for the thrust-vector control loop should be required.

All precise approaches were flown in clear air. A limited nonlinear simulation study showed that even with the deadband and lag in the sideslip feedback path, no significant handling-qualities problems were introduced with simulated turbulence. The issues of ride qualities and rejection of disturbances in the presence of atmospheric



The **X-31A Airplane** was operated with thrust vectoring in a quasi-tailless mode to test and demonstrate advanced control concepts.

turbulence would be better addressed with a real tailless or reduced-tail vehicle. Because of limitations on frequency response and fidelity, the in-flight quasi-tailless system is not accurate enough to reproduce the true directionally unstable behavior characteristic of the response of an aircraft to turbulence.

A reasonable approach to the engine-out failure condition must be developed. If this approach is to include emergency devices that would be deployed to regain directional stability, then the cost, weight, and complexity of such devices must be considered. The cost and weight of adding a thrust-vector system are being reduced by production of axisymmetric thrust-vectoring engines. The X-31A quasi-tailless flight test experiment showed that tailless and reduced-tail fighter-type airplanes are feasible. When the thrust-vectoring capability and reduced-tail configuration are incorporated into the design from the beginning, the benefits of lower drag, reduced structural complexity, and reduced radar cross section could, potentially, outweigh the concomitant added complexity.

This work was done by John Bosworth and Patrick Stoliker of **Dryden Flight Research Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category. DRC-96-12*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Less time is spent in preparation and cleanup.

John F. Kennedy Space Center, Florida

An improved suit to be worn by a worker during abrasive blasting has been developed. Denoted an environmentally controlled abrasive-blasting suit (ECAB), it provides comprehensive protection that, heretofore, has been afforded by a set of special under- and over-garments (including a helmet) and a respirator. These garments and the respirator must be donned in a time-consuming "suit-up" procedure before abrasive blasting. After blasting, the worker must not only doff the garments and respirator but must also shower and the garments must be laundered before they are used again. In contrast, donning the ECAB takes less "suit-up" time, there in no need to wear special undergarments inside the ECAB, there is no need for a respirator, it is not necessary to shower after doffing the ECAB, and the suit does not require laundering prior to reuse.

The ECAB (see figure) is an ensemble that forms a closed envelope to isolate the worker from the hazards of the abrasive-blasting environment. The design of the ECAB also reflects a concern for mobility and comfort to increase the worker's endurance. The ensemble includes a helmet, a coverall, detachable gloves, detachable boots, plus detachable hoses and a manifold for supplying and distributing air for both breathing and cooling. The helmet features a transparent visor and disposable blast shields.

The arms and legs of the coverall terminate in special cuffs designed for attachment and detachment of the gloves and boots. A similar provision is made for attachment and detachment of the helmet. The coverall materials are capable of withstanding impacts by abrasive particles that bounce back from the workpiece. The gloves are flexible enough to enable the worker to operate the abrasive-blasting equipment with ease. The boots are soled and sized to accept safety shoes or boots.

The **ECAB Protects the Worker** from the hazards of abrasive blasting, and offers advantages over older, multiple-garment protective ensembles.

All attachment/detachment cuffs include seals to prevent the entry of abrasive particles into the suit. Relief valves allow air to flow out of the suit but resist the inflow of atmospheric air, thereby helping to maintain a slight positive pressure of supplied air within the suit.

The ECAB is designed and built to provide long-term multiple use.

This work was done by Raymond A. Anderson and Robert E. Persson formerly of EG&G Florida, Inc., for **Kennedy Space Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Bio-Medical category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Technology Programs and Commercialization Office, Kennedy Space Center, (407) 867-6373. Refer to KSC-11868.

Exoskeletal System for Neuromuscular Rehabilitation

This system could help a neurally impaired patient regain the ability to walk.

NASA's Jet Propulsion Laboratory, Pasadena, California

A system of sensors and actuators designed to fit on the lower extremities of human patients and astronauts like an exoskeleton is under development to serve diverse purposes in neuromuscular research and rehabilitation. This system will be operated under both Earth and microgravity conditions. A product of integrated research efforts in several fields of science and engineering, the design of the system incorporates advances in microsensors, robotics, and mathematical modeling of the dynamics of walking. The design of the system has been guided by research findings that show that the spinal cord (even when cut off from the brain by injury) is capable of relearning the ability to walk.

The system could be used by an astronaut exercising in space under the conditions of microgravity to help maintain normal locomotion skills, muscle mass, and bone calcium levels. On Earth, the same system could be used for the rehabilitation of stroke or spinal-cord-injured patients in an effort to restore part or all of their ability to walk.

At present, one way to perform such rehabilitation is to suspend the patient in a harness over a treadmill so that their

legs bear only part of their entire weight while therapists manipulate the patient's legs to assist in stepping on the running treadmill. As the patient gains more ability to step, the amount of assistance needed is decreased. The disadvantages of this approach are several: a limited number of therapists can assist only a small number of patients, the assisted movements are only approximations of normal stepping motions, and there is no way to quantify changes in the amount of assistance needed. Thus, there is a need for something that can accurately measure limb motions, apply and measure controlled forces and torques, and be used to manipulate an entire leg in normal kinematic patterns and speeds. Such a device could be used to study more subjects with greater thoroughness and precision, and could make it possible to rehabilitate more patients with higher levels of success than can now be attained with human assistance alone. Such a robotic device could also be used to preserve normal locomotion skills for astronauts during long-term microgravity conditions.

The present exoskeletal system is a prototype of such a robotic device. Encouraging results have been obtained in preliminary tests performed on humans in the Neurological Rehabilitation and Research Unit of the University of California at Los Angeles. When the system is fully developed, continuous analysis and control of the force and torque actuators needed for normal walking motions will be generated from a combination of dynamical motion modeling and sensory feedback from the exoskeleton.

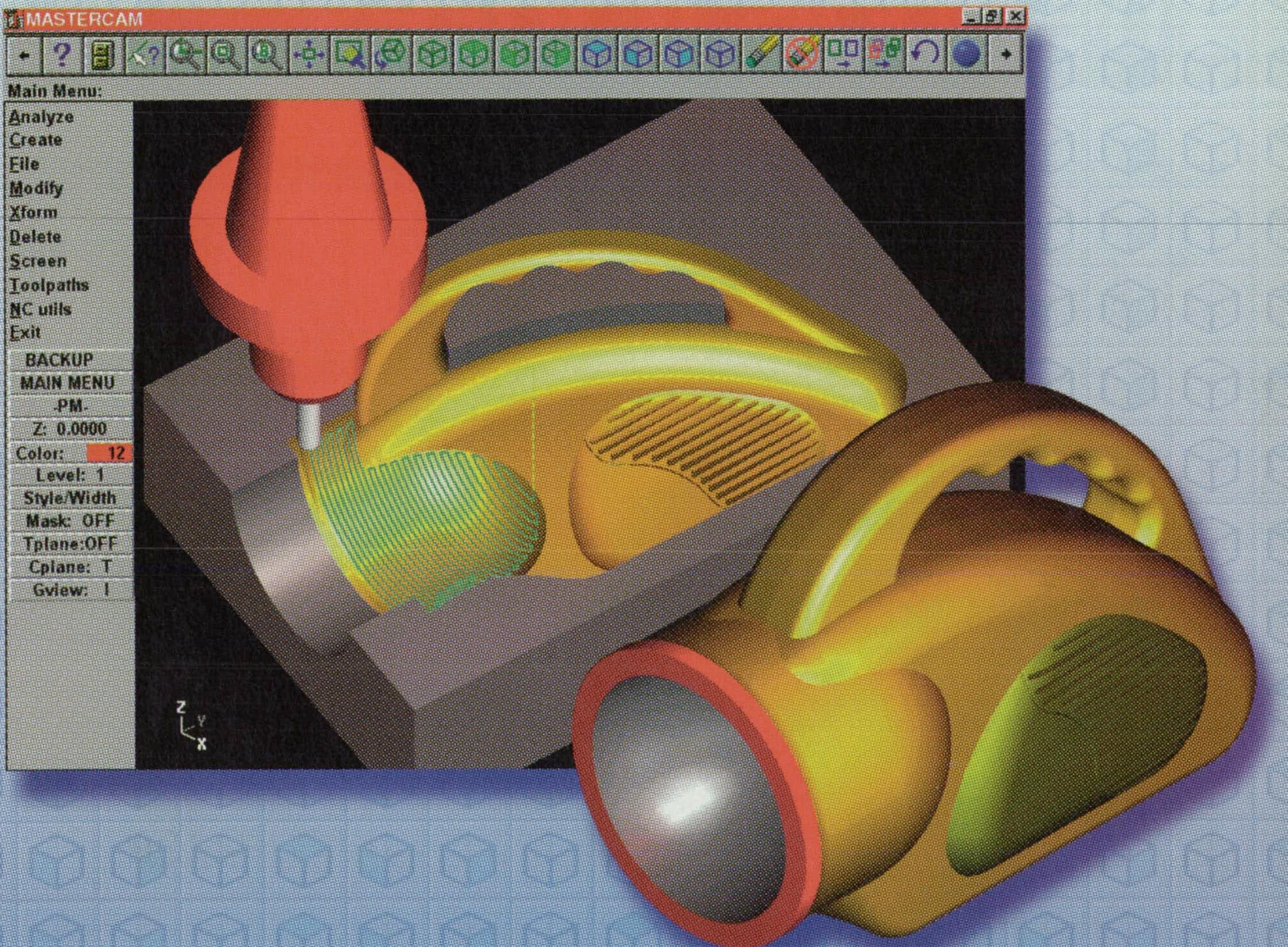
Thus, the development of the exoskeletal system involves the parallel development of sensors capable of measuring six degrees of freedom and computational resources capable of instantaneous analysis and control. This approach uses the exoskeleton to control and monitor the movements of each segment of the lower limb during locomotion and a mathematical model that accounts for such details as the masses and kinetics of limbs and the moment arms of individual muscles of the knee, hip, and ankle. Variables that can be investigated by use of the model include the percent of body weight loading, the frequency of stepping, the speed of walking, and changes in muscle output that would occur in hypertrophy or atrophy.

This work was done by James Weiss, Antal Bejczy, Bruno Jau, and Gerald Lilienthal of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Bio-Medical category.*

NPO-20370

May 1999

Rapid Product Development



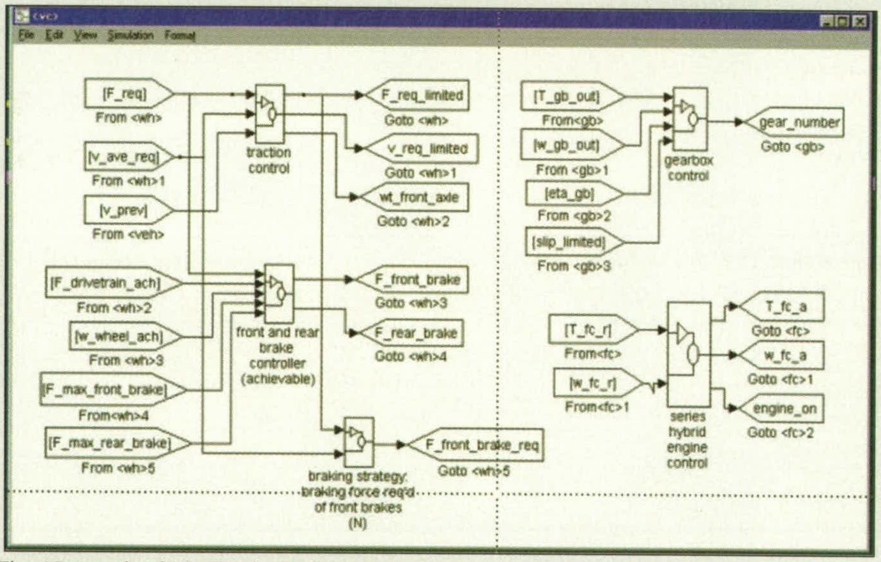
Mastercam Solids solid modeling software from CNC Software, Tolland, CT, can be combined with Mastercam Mill to create and machine solids in a single integrated interface. In this example, the flashlight was removed from a mold block to create a cavity, and a toolpath was applied. See New Products (page 10b) for more information. (Image courtesy of CNC Software)

Designing a Hybrid Electric Vehicle: The Tools it Takes

The quest to produce a hybrid electric vehicle (HEV) challenges the imaginations of automotive engineers around the world. Numerous configurations must be weeded out and prototypes are prohibitively expensive. These design problems seem tailor-made for tools such as MATLAB, Simulink, Stateflow, and Real-Time Workshop, a suite of design tools from The MathWorks, Natick, MA. Using these tools, auto engineers can swap engines and battery banks, try different chassis combinations, and make decisions that will guide future design efforts for cars that don't yet exist.

Already, two major players in the national effort to build an HEV have created simulators based on The MathWorks products that have become mainstays in HEV design. The ADvanced VehIcle SimulatOR (ADVISOR), developed at The National Renewable Energy Laboratory (NREL) in Golden, CO, and the PNGV Analysis Toolkit from Southwest Research Institute (SwRI) in San Antonio, TX, both take advantage of Simulink's user-friendly, object-oriented environment for developing models, performing dynamic system simulations, and designing and testing new ideas. The tools have set the course for HEV development at national labs, universities, and among the Big Three auto makers.

"This is the next step toward realizing the development of these vehicles," said Scott McBroom, Senior Research Engineer at SwRI. "We're convinced this is the way to go."



The ADvanced VehIcle SimulatOR (ADVISOR) takes advantage of Simulink's user-friendly, object-oriented environment. (Courtesy of Keith Wipke, NRRL)

In Pursuit of a Cleaner Car

The nation's effort to build practical and efficient hybrid electric cars by 2004 began in earnest with software developers involved in the Partnership for a New Generation of Vehicles (PNGV), a government initiative announced by President Clinton in 1993. With increasing U.S. dependence on foreign oil — most of which is used to fuel America's cars — and increased awareness of the perils of air pollution, alternate transportation had risen to national attention. Hybrid vehicles seem to offer the best hope of a near-term solution. Computer models and early prototypes indicate that HEVs will boost fuel economy and cut emissions, while still providing the safety, performance, and range that American drivers demand.

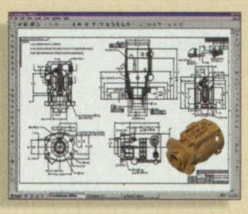
Under the PNGV program, NREL entered into contracts with Ford, General Motors, and Chrysler to produce hybrid propulsion systems by 1998, first-generation prototypes by 2000, and market-ready HEVs by 2003. In addition to the industrial partnerships, NREL has sponsored HEV research at the nation's leading engineering schools.

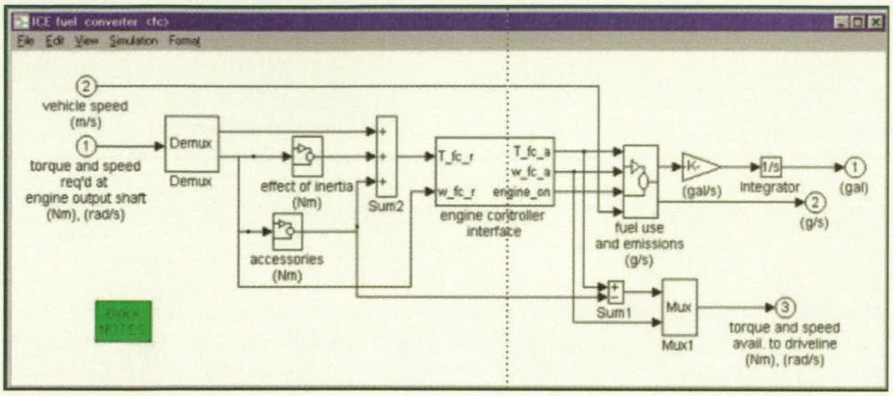
Engineers at the Big Three auto makers are pushing to meet PNGVs lofty goal of tripling conventional gas mileage to around 80 miles per gallon. Chrysler, which joined the initiative in 1996, is still in the modeling phase, while GM and Ford, which have been in the program since 1993, are testing their concepts on mule vehicles. More than 20 organizations currently use ADVISOR, and the tool is continuously fed up-to-date component test data through user and university validation efforts.

What's Under the Hood?

Hybrid vehicles use an electric motor and a bank of high-voltage batteries in conjunction with a "heat" engine, usually a conventional internal combustion engine (ICE). The components are arranged either in parallel or series configurations. Computer modeling with ADVISOR has already shown some basic characteristics for each.

In a parallel hybrid vehicle, both the electric motor and the ICE are con-





Simulink control block diagram for ADVISOR vehicle simulator. (Courtesy of Keith Wipke, NRRL)

nected mechanically to the drive wheels. The ICE provides supplementary power when the vehicle is accelerating or climbing steep grades. Parallel HEVs don't need generators and have lower mass and better highway efficiency. They have the added benefit of redundant drive power, meaning the car can still be driven if one of the power systems fails. Parallel vehicles require a complicated mechanical coupling and a multi-speed transmission. Because the ICE must perform over a range of speeds, tuning can be difficult and efficiency is diminished.

In a series HEV, only the electric motor drives the wheels. The ICE runs an alternator, providing power to the electric motor and the battery bank. Series HEVs have simpler mechanics, allowing more freedom for component placement. Because the electric motor provides enough torque throughout the range of required speeds, a single-speed gearbox can take the place of the transmission. Full power is available at all times in a series HEV, and because the ICE runs only when the batteries need charging, it can be tuned to run efficiently at a single RPM. Because series HEVs lack the redundant drive systems of their parallel counterparts, they are extremely sensitive to battery and electric motor efficiency. Some vehicles may have trouble negotiating long, uphill grades.

For the two basic HEV configurations, there are a number of control strategies not found in conventional vehicles. While the efficiencies of each component are important, it is the way they are interconnected that really determines the value of an HEV design. Enter ADVISOR, with its ability to model all of the HEV components, monitor their interaction and response, and output the performance data.

"There are many ways to design these systems, and if you were to design and build each one individually and test it, it would require an enormous amount of time and money," said Dr. Larry Michaels, Application Engineering Manager at The MathWorks. "By modeling on computer, you can evaluate all of these configurations very quickly and very cost effectively."

Virtual Trial and Error

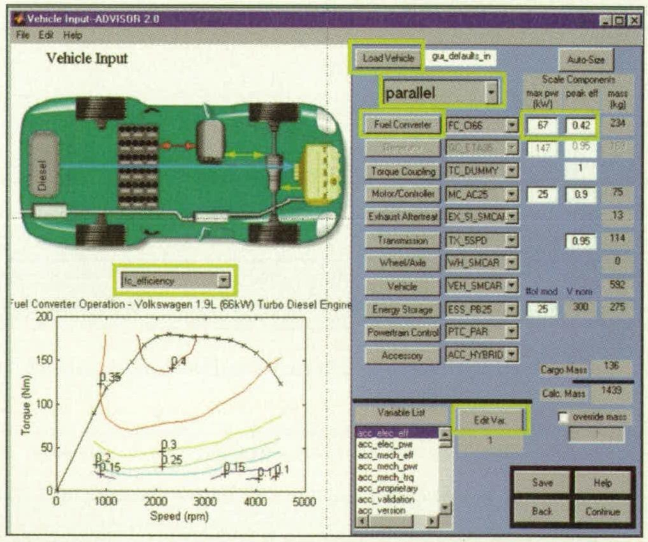
ADVISOR is termed "steady-state" and "backward-looking" because its simulations begin with desired outputs and work back toward component choices and configurations. "You're trying to get into the ballpark with ADVISOR," added Dr. Michaels. "Trying to find a configuration that looks promising and that will meet performance and fuel economy goals. The idea is to see if this configuration should be pursued further and then to build prototypes based on that idea. Many times the negative answers are more important than the positive answers. The computer model is a way to quickly and easily see if you are ever going to get what you want out of it. Sometimes, even under ideal conditions, it won't meet goals. That idea can then be discarded."

According to NREL's Tony Markel, ADVISOR, with all of the components modeled, allows HEV designers to use a variety of standard and custom driving cycles like the Federal Urban Driving Schedule (FUDS) and the Federal Highway Driving Schedule (FHDS). With the power of Simulink, ADVISOR easily can handle battery state-of-charge corrections and vehicle soak periods. The simulator gives designers quick and accurate assessments of important vehicle performances such as fuel economy, emissions, acceleration, and grade sustainability. ADVISOR results can then be run through MATLAB to find equilibrium points or ideal operating conditions.

ADVISOR's Graphical User Interface (GUI) is designed to facilitate entry and modification of elements such as drivetrain configuration, transmission, vehicle type, energy storage system, generator, driving cycle, control strategy, and scaling. The GUI corresponds to a top-level Simulink block diagram, which shows the model's data flow from trip, through road load, driveline, motor and energy storage, and on to numeric outputs for fuels used and tailpipe emissions. Looking down two layers into the "road load" subsystem shows the interaction of next required speed and previous speed through other subsystems representing roll, climb, aerodynamics, and acceleration to arrive at figures for torque and speed required at the virtual vehicle's "wheels."

On the Virtual Road

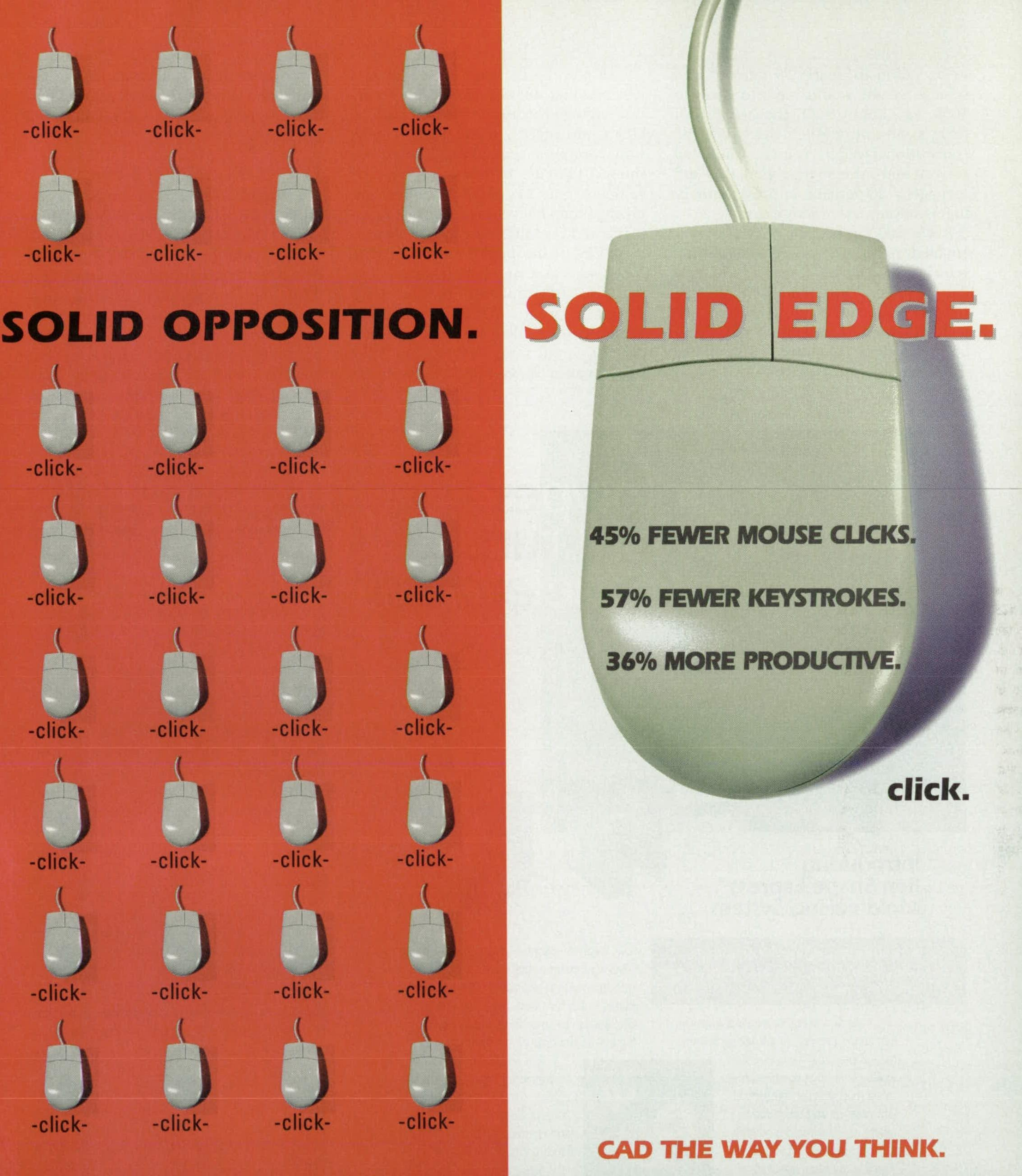
In 1996, NREL tested five vehicle configurations with ADVISOR in pursuit of PNGV's goal of 80 mpg. These included three lightweight (series, parallel, and ICE) and two conventional-weight (parallel and ICE) configurations. Simulink's block group modeling platform allowed designers to easily manipulate each component and find the strengths and weaknesses of each design. Using ADVISOR, NREL engineers found that parallel and series



Vehicle parameter input screen for ADVISOR vehicle simulator, developed in MATLAB/Simulink Environment. (Courtesy of Keith Wipke, NRRL)

vehicles showed the same fuel economy sensitivity to most parameters, but series vehicles were three times more sensitive to battery and electric motor efficiency.

Results also showed that to reach the 80 mpg goal, ICE efficiency would have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45% FEWER MOUSE CLICKS.
57% FEWER KEYSTROKES.
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to be raised to nearly 35 percent and vehicle weight would have to drop to 1000 kg, about half the weight of today's conventional vehicles. While the conventional-weight vehicles modeled did not make the 80 mpg goal, they did manage a 20-percent improvement in fuel economy over today's cars.

According to Markel, ADVISOR has enabled NREL to specify 176 distinct vehicles for evaluation, verification, and data storage. The findings may drive research into battery and electric motor technology, and accelerate NREL's goal of having most metal auto components made of aluminum by 2015.

Last year, NREL used ADVISOR in a new test that allowed for different control strategies in the series and parallel HEVs, an analysis made feasible only with computer simulation. These tests showed that the best-designed parallel vehicles got 24 percent better gas mileage than conventional cars, surpassing its series counterpart by 4 percent.

ADVISOR has been well-validated at NREL and at a number of universities that use the simulator in their HEV design programs. ADVISOR's findings generally have fallen within 2 to 4 percent of actual measurements on HEV prototypes. A validation study at Virginia Tech in 1997 found that "the validation process shows that ADVISOR has extensive values as a simulation tool for HEVs."

Forward-Looking Design

Software engineers at SwRI began looking for a way to take HEV development beyond steady-state, backward-looking models like ADVISOR, and offer a dynamic environment for designing, testing, and proving their ideas without hardware prototypes. SwRI used Simulink to put together modular component libraries of engines, vehicles, mechanical couplings, driveline components, energy storage devices, and a number of other HEV essentials.

At the direction of The United States Council for Automotive Research (USCAR) — a legalized consortium of Ford, General Motors, and Chrysler — SwRI used those libraries as the foundation for their PNGV Analysis Toolkit. Participants in the PNGV since its inception, engineers in SwRIs Engine and Vehicle Research Division, were familiar with most of the widely used HEV simulators, including Simple-V and ADVISOR. SwRI chose MATLAB and Simulink for their PNGV Analysis Toolkit because of programming efficiency, Simulink's self-documenting feature, and customer familiarity with the software.

Both the PNGV Toolkit's GUIs and the block diagrams go beyond simple choices of components, and require detailed descriptions of the components' performance values, allowing the HEV's subsystems to be tested. According to Ashok Nedungadi of SwRI, despite the dense models, the use of MATLAB GUIs "allows a novice to use the tool."

The PNGV Analysis Toolkit is being used to evaluate new drivetrain options, test and debug control strategies, size and specify sub-components, and evaluate software and hardware modifications. USCAR now owns the software. Its members, who are engineers at the Big Three auto makers, will now be using the PNGV Toolkit to develop HEVs that meet PNGV's goals. Michaels agreed that new, dynamic, forward-looking simulators offer the best chance for both fine-tuning HEV components and designing and testing control strategies between them.

For more information, contact The MathWorks at 24 Prime Park Way, Natick, MA 01760; Tel: 508-647-7000; Fax: 508-647-7101; e-mail: info@mathworks.com; www.mathworks.com.

Turning Information into Knowledge

IBM and Enovia Build a Corporate Knowledge Base

The need for today's corporations to innovate is becoming increasingly critical to their survival as competition increases globally. Delivering products with a consistent level of quality and in an efficient manner might ensure positive revenue, but it does not ensure the maintenance or growth of market share. With an increasing number of competitors — which employ the latest technologies to ensure manufacturing efficiency — revenue growth can occur most rapidly by increasing the size of existing markets. Increasing market size and market share can be ensured by consistently launching products that are dynamic, fresh, and desirable.

Core objectives for a corporation include not only reducing the cost of developing new products, but also increasing the speed with which new products can be brought into existing markets. Launching new products quickly requires an environment that facilitates cost reduction, and encourages and supports innovation.

Significant progress has been made in reducing product development costs. Use of modern computer-aided design (CAD) tools has allowed design engineers to more efficiently create a detailed product definition. With digital mock-up technologies, product designs can be validated before cutting any metal. Similarly, implementation of product data management technology has enabled increased access to product information.

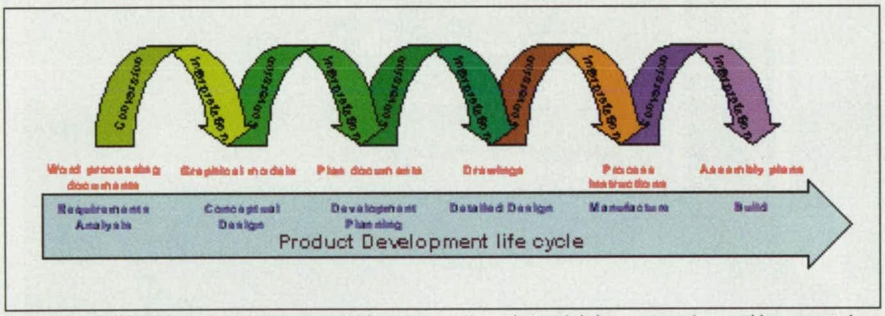


Figure 1. Traditional product development lifecycles require substantial data conversion and interpretation.

This progress, however, has focused on the production engine within a business rather than on the innovation engine. Even though CAD systems enable designers to create information faster, the number of new products a company can create is constrained by business processes and other systems.

For example, designers often are not able to view manufacturing constraints and the impact of these constraints on their design efforts. Thus, though parts of the process may be automated and supported by digital data, the overall process, which involves other departments within the organization, does not function smoothly or efficiently. As a result, the time required for analysis and justification of new products constrains the number of new products that can be introduced in a given period of time.

Innovation Requires Change

Today's serial development processes generate and utilize large amounts of product information, but prevent corporations from developing product knowledge. Serial development processes consist of several sequential stages, each of which uses information from the previous stage, and generates information to be used in subsequent stages. Between each stage, information must be transferred to other people and departments, re-interpreted, and converted into a format expected by that department. The data conversion and interpretation comprise a significant portion of the time consumed by the product development process.

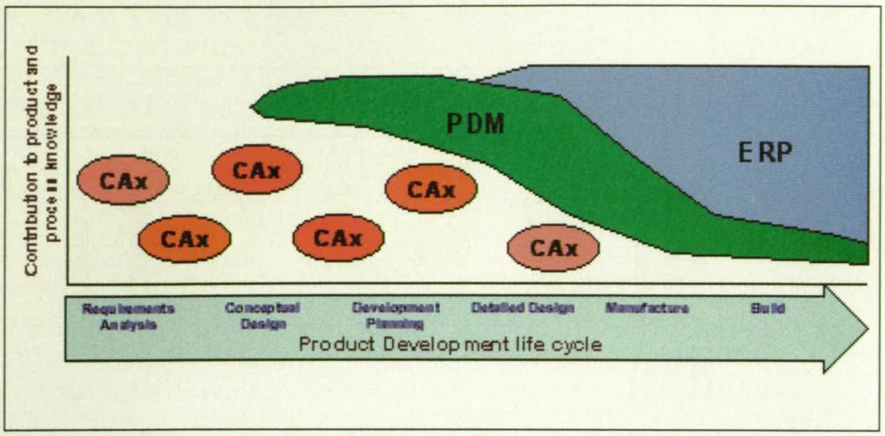


Figure 2. CAD, PDM, and BRP all contribute during different phases of product development.

CAD and other tools support product definition and enable more rapid transformation from one format to another. Product data management (PDM) provides a single location from which to access information, thus minimizing time consumed by data transfer. Enterprise resource planning (ERP) systems integrate data and processes associated with manufacturing planning and assembly of the product. These technologies contribute more strongly during different portions of the product development process towards compressing the product lifecycle. Despite their benefits, they do not eliminate the re-interpretation required by various departments involved in a serial development process, and do not encourage parallel development activities.

To maximize compression of the product development lifecycle, companies must not only represent product data in digital format, but they must also ensure that multiple departments can interpret the information easily and unambiguously. Secondly, they must re-architect their product development process to allow multiple disciplines to not only access product knowledge at any point in the process, but to productively utilize that knowledge to progress their portion of the overall product development lifecycle. This activity can be undertaken with a consolidated focus on the drivers that have the greatest bearing on reducing cycle time and cost of creating new products, while more efficiently employing available resources. For example, allowing the design, analysis, manufacturing, and maintenance disciplines to define their respective deliverables in concert would have an enormous bearing on the overall cycle time by consolidating the influence each of these disciplines has on the product itself.

A New Era

Today, the tools exist to define product information so that it can be utilized by all disciplines involved in the product development process at any time during that process. Successful utilization of these tools requires working in a new way. First, companies must define product information in a context within which multiple disciplines can access it and utilize it productively. In this form, it becomes corporate knowledge. Secondly, companies must design processes so that participants can perform their roles in the product development process without the need for completely mature information. This allows departments to work in parallel. As

information matures, each department revises its work, if necessary, based upon any new information.

The tools for collecting, storing, organizing, managing, and giving access to product and process knowledge make up a new environment referred to as Virtual Product Development Management (VPDM).

This type of corporate transformation represents a significant paradigm shift. Product development processes have evolved over decades; changing them, even slowly, is difficult. By automating tasks and allowing enterprise information sharing, CAD and PDM systems deliver significant reductions in cycle time. But to move to the next level of competitiveness through product innovation, companies must think about product development in a new way.

The Corporate Knowledge Base

The core concept lies in focusing the product, resource, and process modeling environments to foster communication. Multiple disciplines must be able to work in parallel, accessing and utilizing information from a corporate knowledge base. This knowledge base will contain an entire product definition, including processes required to build the product, as well as plant designs for the factories in which manufacturing will take place. The traditional handoff of data no longer will be necessary, nor will the data conversion and re-interpretation that typically accompany them.

Because downstream disciplines can define information before designs are complete, design engineers can utilize this information to perform intelligent product simulations. They can understand performance, manufacturing processes, and maintainability constraints, all of which are relevant to the initial product design. Changes to the design that occur early in the design cycle are orders of magnitude less expensive than those made after the product is released. Moreover, the design is able to mature more quickly, compressing traditional product development processes.

Providing the Answer

To create collaborative, innovative design environments, companies must think about product development in a new way. They also require specific tools that enable creation and accumulation of product knowledge.

ENOVIAVPM is a software solution that addresses the needs of companies wanting to increase the size of their markets by developing innovative products faster. The primary objective of ENOVIAVPM is to optimize end-to-end development of competitive and innovative products — in effect, to create better products.

To optimize products and processes, ENOVIAVPM provides a high degree of collaboration. This includes simultaneously defining, configuring, and optimizing product definition, manufacturing process, and product operations, and propagating changes consistently through the entire product and process definition. To capture and access knowledge during the product development process, ENOVIAVPM manages product information such as features and relationships generated by tools such as assembly and configuration modelers.

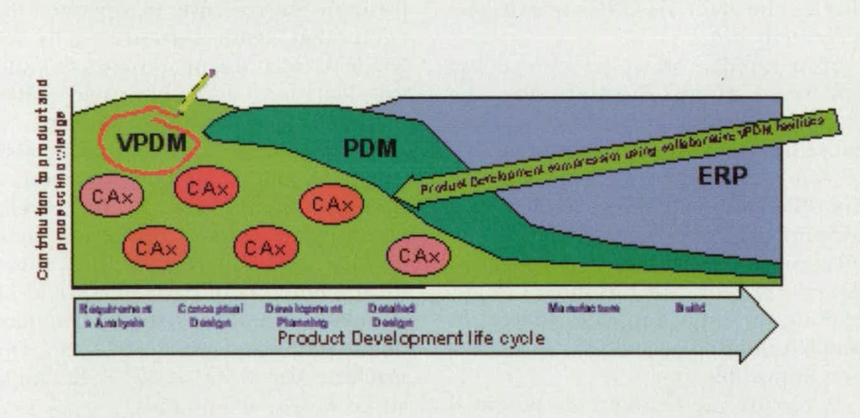


Figure 3. A knowledge-based environment in which multiple disciplines interact to define a product and how it will be manufactured facilitates innovation and compresses the product development lifecycle.

ENOVIAVPM achieves these objectives by delivering the following capabilities:

- A data model uniquely tailored to properly model and represent a virtual product definition;
- Generic configuration management capability, which can co-configure a large cross-section of data, from specifications to technological links, dependencies, and manufacturing and maintenance instructions;
- Action flow mechanism tailored to facilitate communication and control, especially during phases of the product development cycle where a large quantity of change occurs;
- Maturity management capability, better suited to promote controlled data sharing in a concurrent design and product development environment;
- Publish and subscribe capability, which enables individuals to pull information passively, and subsequently automate responses accordingly;
- Technical publication applications, which allow maturity, versioning, configuration management, and generation capabilities to documents at the paragraph level. This capability is particularly useful for specifications, assembly instructions, published bills of material, and maintenance operations.

Bringing It All Together

Software alone is rarely sufficient to deliver substantial corporate-wide benefits, especially given the paradigm shift required to fully leverage the power of ENOVIAVPM. To prepare the organization for effective utilization of a tool such as ENOVIAVPM, a company must first examine business objectives to ensure that increasing market size is the proper goal. Secondly, a company must analyze existing processes to determine where process linkages between departments are weak. Next, these processes must be re-engineered to ensure that multiple disciplines can interact to simultaneously define and simulate a product. Finally, the proper tools must be implemented, along with other required complementary products, such as network management, load balancing, and backup and archive. All of these tools must be integrated carefully with legacy applications in a manner that does not disrupt normal day-to-day operations.

These steps will enable a company to realize the tremendous benefits that can be derived from improving its ability to innovate. IBM and ENOVIA can help a company not only start its innovation engine, but bridge the gap between its innovation and production capabilities. The resulting environment encourages involvement from all disciplines in the entire product development process.

This article was written by Steve Shoaf, IBM PDM II Solutions Manager, North America. For more information, contact ENOVIA Corporation, Charlotte, NC, at 877-ENOVIA2 or 704-944-8888; www.enovia.com.

3D Tool for Modeling Early-Stage Designs

An innovative method makes possible low-cost "rough-draft" models at early stages of the design process.

Z Corporation, Somerville, Massachusetts

The allure of a convenient method to quickly produce low-cost concept models is powerful. Such a method could not only replace existing modeling techniques but would offer a means to make many more models than ever before and thus would foster creativity and innovation. The problem is that most of the conventional methods as well as the so-called "rapid prototyping" tools do not address the needs of the early stages of the product development process.

A 3D modeling tool should be useful at the earliest stages of design and allow for many "rough draft" designs. Many iterations of any proposed design will ideally be seen only by the designer, before he or she is ready to have the design critiqued by others. In order for this tool to be practical, it must be easy enough to use that the designer has the luxury of making a model just for a quick look.

It must be fast enough to fit within the existing design process—for example, a designer must be able to print a model during a one-hour lunch. To deliver on speed, the system must also be easily accessible to the designer. If the part can be produced in one hour, but must be made at a remote location and delivered, the first advantage does little good.

The models must be cheap: the majority may have extremely short lives before ending up in the trash. This means that the total cost per model, including capital cost, materials, and maintenance, must be low enough that the designer is not inhibited from making twenty or so iterative design models on a given project.

Finally, if this model is to serve as the basis for a decision, it must also accurately represent the design. The importance of the ability to build complex geometries, such as undercuts, overhangs, cores, and inner passages, is obvious. The designer needs to evaluate the actual design, not a simplification resulting from the limitations of the fabrication method.

Based on these criteria—speed, cost, ease of use, and the ability to fabricate complex geometries—nearly every modeling technique fails the test. Conventional model-making methods such as cutting of foam core, molding of clay, or handwork of wood are very time-consuming, especially when the communication with their remote location is taken into account. They are labor-intensive and hence inherently expensive.

Finally, all these methods are limited in the types of geometries that can be made. CNC machining is neither simple to use nor fast enough to be practical for early-stage concept models; it also requires the designer to interface with a shop group in a distant location with its own backlog of work. In addition, the types of geometries that can be made via CNC are extremely limited.

Most rapid prototyping systems are not rapid at all. Furthermore, the equipment and materials are generally exceedingly expensive, while the systems are difficult to use and most are not office-compatible. While rapid prototyping provides true CAD design verification, since the digital data is used directly to fabricate the model, many techniques use support structures which render true model representation impossible.

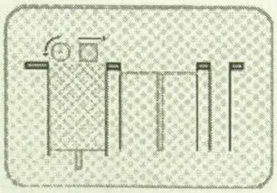
While the gap between the potential of iterative modeling and the reality of the tools available seems daunting, there is a new technology that is able to cross this chasm. It is a very fast, inexpensive, and surprisingly simple tool which can build complex three-dimensional objects directly from a CAD file.

Z Corporation has commercialized a technology that radically streamlines the process of building three-dimensional models automatically from CAD files. The Z402™ system, based on the Massachusetts Institute of Technology's patented 3DP™ technology, is an affordable 3D printer. The system builds parts out of a starch-based powder and aqueous binder in an office environment, thereby providing engineers, marketers, and manufacturers a means to communicate and improve designs in three dimensions instead of on a flat screen or paper. The Z402 system is about 10-20 times faster than any competing rapid prototyping technology, making it a powerful tool for reducing the time required to bring a new product from conceptualization to market. For example, the build time for a part with dimensions of 8" × 4" × 1.5" is about 45 minutes.

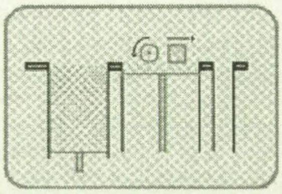
In addition to its speed, which has set a new standard in the rapid prototyping industry, the Z402 system is surprisingly inexpensive to operate: the equipment (with software) sells for $59,000, and the materials generally total less than a dollar per cubic inch of part, and often as little as 50 cents.

Finally, the Z402 system has the ability to produce complex geometries with no supports, since all stressed elements have support from unbound powder until fully cured. This allows for the building of parts that would be impossible on other systems. The maximum part size is 8" × 10" × 8". The machine size is 29" × 36" × 42" high, and it weighs 300 pounds.

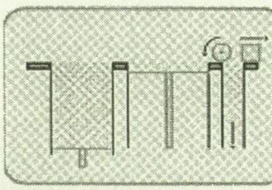
The designer must first export the design from the 3D CAD system into the STL file format. STL is the *de facto* standard file format for all rapid prototyping equipment and approximates the surface of the solid model by covering it with a multitude of small trian-



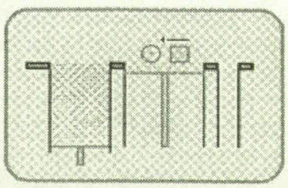
Step 1: As it traverses left to right, the roller collects powder.



Step 2: The roller spreads a thin layer of powder over the build piston.



Step 3: The roller discharges excess powder down the powder overflow chute.



Step 4: As it traverses right to left, the print assembly prints the part cross-section.

gles. Ideally, to make a good rapid prototyping model, the STL file must be made from a watertight solid model. The biggest drawback of the STL format is the magnitude of the file sizes generated, which slows down computer time and uses a lot of memory and disk space. This can be minimized by reducing the number of triangles generated, *i.e.*, increasing their size and therefore reducing the accuracy of the STL file. File-size reduction can be achieved by saving the file as Binary STL instead of ASCII STL. Binary STL is the recommended file format, although either type file can be read by the Z402 system software.

Ready to Print

The user is now ready to 3D-print the part on the Z402 system, which produces the part layer by layer from powder that is bound by a proprietary liquid binder. Minimal training on hardware and software is needed to operate the system. The user first fills the machine with powder, and then imports the STL file into the Z402 system software, a Windows™-based application that can run on a standard ($1500) Pentium PC. The Z402 system software slices the STL file into cross-sections that can be anywhere between 0.005" and 0.010" thick. The user, in selecting the layer thickness, makes a tradeoff between resolution (stair-stepping) and print speed.

The Z402 system then prints these cross-sections one after another from the bottom of the design to the top. Inside the Z402 machine there are two pistons, as shown in the diagram. The feed piston is on the left and is shown in the 'down' position filled with powder. The build piston is the piston on the right, shown in the 'up' position. Also represented in the diagram is the roller (drawn as a circle) and the print assembly (drawn as a square.)

To begin the 3D printing process, the print assembly moves to the right and spreads a layer of powder in the same thickness as the cross section to be printed. Then, as the print assembly returns to the left, the 128 jets in the Z402 binder cartridge apply a binder solution to the powder, causing the powder particles to bind to one another in the shape of the cross-section of the layer. The feed piston comes up one layer of thickness and the build piston drops one more layer of the thickness. The Z402 system then spreads a new layer of powder and repeats the process until the part is completely printed.

At this point the build box is filled with powder, some of which is loose and some of which is bonded to form the part. The excess powder is removed with a vacuum hose and then the part is picked out from the loose powder and depowdered in a post-processing unit. The part can be infiltrated with various materials to improve its strength and surface finish. The standard method of infiltration is a quick dip in wax; however, Z Corporation recently released a new materials system that makes concept models so strong that they can support the weight of a person. Parts made with the new materials can be sanded, painted, drilled, tapped, and finished in a number of ways for even higher-quality models. The key to the new materials system is the use of ZR10 resin for infiltrating the part. The resin, which is applied by using a simple hand-held applicator, cures in 20-40 minutes, depending on the size of the part.

Very fast 3D printing allows for design verification by the designer. It also provides a means for communication between the designer and the design supervisor, or other designers working on products which will interface with each other. By providing almost instantaneous feedback on each proposed design change, the Z402 system allows the designer to make more iterations of a design at a faster rate.

Carefree 3D printing improves communication with the marketing department and can provide feedback from potential customers at a stage in the design cycle when changes are inexpensive and easy to implement.

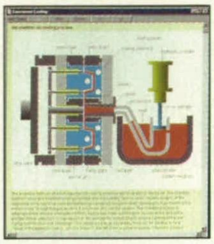
Finally, 3D printing early in the design cycle also provides improved communication with the manufacturing group, which results in early detection of flaws and improved design for manufacturing.

The Z402 system can transform 3D modeling into an indispensable, everyday adjunct to the inherently limited 2D visualization provided by computer screens and printouts. The Z402 system will improve part visualization and communications while enhancing creativity and reducing the number of design flaws. Z Corp. can be found on the Internet at www.zcorp.com.

For more information, please contact the author of this brief, Marina Hatsopoulos, at Z Corp., 35 Medford St., Suite 213, Somerville, MA 02143; (617) 628-2781; fax: (617) 628-2879; E-mail: marina@zcorp.com; www.zcorp.com. *Z402 is a trademark of Z Corporation. 3DP is a trademark of the Massachusetts Institute of Technology. Windows is a trademark of the Microsoft Corporation.*

NEW PRODUCTS

Software Estimates Part Cost



Boothroyd Dewhurst, Wakefield, RI, has released DFM Concurrent Costing software, which analyzes a range of manufacturing processes, including hot forging, cold or hot die casting, powder metal processing, sand casting, and investment casting, allowing engineers to estimate the cost of producing a part. It provides information on manufacturing and material selection, and can be used at both the concept stage and during design decisions, providing a means for exploring alternative design strategies before 3D modeling, prototyping, and other cost-intensive stages of development are reached. A library of secondary operations includes information on finish machining, deburring, surface treatment, and packaging. **Circle No. 740**

Spray Coatings for Tooling

General Magnaplate Corp., Linden, NJ, offers Plasmadize® 2139, a series of thermal spray release coatings for metallic and non-metallic tooling. The coatings are designed to replace toxic silicone and other sprayed, painted, or dipped one-time release agents. The coatings eliminate the need for cleaning demolded parts. Users can select smooth or matte surfaces, and products can undergo final finishing immediately after demolding. Specific coatings are available for use on Invar and ferrous tooling, aluminum and non-ferrous tooling, fiber reinforced plastic, plaster and plastic tooling, and General Magnaplate's proprietary CMPT™ toolface. **Circle No. 742**

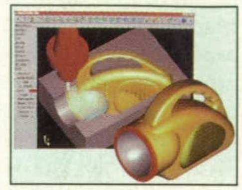
Part-to-CAD Inspection

The ShapeGrabber™ computer-aided inspection system for part-to-CAD verification and inspection from Vitana Corp., Gloucester, Ontario, Canada, includes a scanning head, translation stage, acquisition and inspection software, training, and a PC. The system introduces new technologies to simplify fixturing, streamline scan alignment, and reduce noise. It can scan half a million data points and produce a detailed 3D inspection report in one or two hours for a typical part. Other features include 15,360 points per second digitizing with patented laser scanning technology, 0.001" measurement accuracy, and a choice of motion platforms for parts of virtually any size. The system compares parts and tooling directly to 3D CAD files without requiring dimensional drawings. **Circle No. 746**

Vision Gauge System

The Vision Gauge System from Diversified Engineering & Manufacturing, Orange, CT, is a non-contact optical measuring sensor and controller used to measure or guide product that is produced in a continuous process flow, up to a thickness (diameter) of one inch. The integrated, standalone, measurement/observation/monitoring (MOM) device allows the measurement of width, thickness, diameter, edge, or gap gauge of either opaque or transparent materials. Position or thickness can be monitored down to 0.0002" as the material flows through the system. It features a 5000-pixel CCD linear image sensor with optics and light source in one package. The processed material is passed through the optical window area of the U-shaped frame, where the measurement occurs. A controller provides numeric and bar graph LED monitoring. **Circle No. 744**

Solid Modeling and Machining



CNC Software, Tolland, CT, has released a new version of Mastercam® Solids hybrid solid modeling software that can be used with Mastercam Mill to provide integrated solid modeling and machining. Based on the Parasolid kernel, the software includes functions such as solid body construction, automated filleting and chamfering, thin-wall creation and shelling, and volumetric data. When added to Mastercam Mill, the software allows users to create and machine solids, surfaces, and wireframes, and program multiple types of data as a single model. Users can import Parasolid files as true solids; built-in translators for IGES, VDA, DXF, CADL, STL, and ASCII are included. **Circle No. 733**

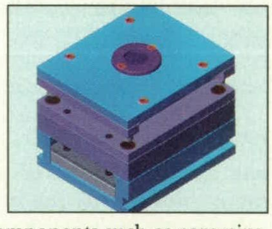
Design Automation Software

POINTER design automation software from Synaps, Atlanta, GA, is a multi-platform design and analysis program that performs nonlinear, multidimensional constrained optimization, and automates the selection process or path to find the best solution for cost-effective product design. Features include three search algorithms: genetic algorithm, downhill simplex, and gradient; an automated training feature; and the ability to link the program to existing executables. The software is designed to exploit flaws in the user's analysis, allowing logical errors to be found and eliminated. **Circle No. 741**

PCB Design Software

PADS Software, Marlborough, MA, offers PADS-PowerPCB 3.0 interconnect software, which enables users to complete complex PCB designs. The software allows electronics manufacturers to speed time-to-volume production. Enhancements include Intelligent Attribute Definition and Control, which provides the ability to intelligently integrate with enterprise resource planning (ERP), manufacturing resource planning (MRP), and product data management (PDM) systems. OLE Automation allows users direct database access with no translation required. Other features include automatic assignment of alphanumeric pins, lock-protect nets, and enhancements to copper pour and test point rules flexibility. **Circle No. 747**

Mold Base Creator



Toolbox/MB for SolidWorks 98Plus from Cimlogic, Nashua, NH, allows SolidWorks users to create mold bases as constrained assemblies. The add-on is fully integrated with SolidWorks 98Plus, and supports the DME A and B series. The software creates complete assemblies in four picks, and includes components such as core pins, ejector pins, A and B plates, dowel pins, locating rings, and bushings. Built-in design tools help users add ejector pins and support pillars. **Circle No. 748**

CAD Software

DATACAD LLC, Avon, CT, has released DataCAD 8.05.01 for Windows 95/98/NT, an updated version of its 32-bit CAD software for 2D/3D applications. The enhanced version provides improved visualization capabilities and new options for customizing the user interface and hardcopy output. Users can map drawing line color to printed line width, density, and color directly from DataCAD using the new Pen Table dialog. An enhanced QuickShader feature provides lighting intensity controls and background color settings. The Drawing Window can be saved as a bitmap image for use in technical presentations. **Circle No. 743**

Single-Crystal YAG Reinforcement Preforms for Refractory Composites

Preforms can be made in net size and shape, with tailored orientation of fibers.

John H. Glenn Research Center, Cleveland, Ohio

Preforms (essentially, shaped mats) of single-crystal yttrium aluminum garnet (YAG) fibers can now be readily fabricated in net size and shape, with tailored orientation of the fibers. These preforms can be used as fiber reinforcements in ceramic- and metal-matrix composite materials that withstand temperatures as high as 1,700 °C. The development of these preforms and composites is a continuing effort in conjunction with other efforts to develop lightweight components for aircraft turbine engines.

The single-crystal form of YAG is needed for creep resistance; the polycrystalline forms of YAG and other oxide fiber materials do not resist creep adequately at the contemplated high operating temperatures. It would be expensive and impractical to construct preforms by weaving, braiding, or laminating premanufactured single-crystal fibers, and handling of the fibers during such construction would weaken them.

A proprietary process is being developed to overcome the above-mentioned limitations. In this process, reinforcement preforms are formed to net-shape, eliminating the need for operations such as weaving and braiding of single filaments. The net-shape preforms can have random, oriented, or mixed reinforcement in selective areas. Reinforcement volume-fraction shape and orientation can be controlled. Thin complex parts such as airfoils can be fabricated. Single-crystal porous preforms with volume percent in the range of 30 to 54 percent and strut dimensions in the range of 10 to 125 micrometers have been produced.

Figure 1 shows a scanning electron micrograph of porous single-crystal YAG reinforcement. Figure 2 shows a Laue x-ray diffraction pattern from this porous YAG preform. The Laue x-ray pattern is characteristic of single-crystal YAG, thus proving its single-crystal nature. High magnification microscopy indicated the absence of grain boundaries and confirmed the single-crystal nature. Reinforcement preforms with random, unidirectional and [0/90] reinforcement have been fabricated so far. Sufficient permeability of the preforms was demonstrated by conducting infiltration of the preform by polymer and metal matrices by pressure infiltration. Work is underway to optimize the preform rein-

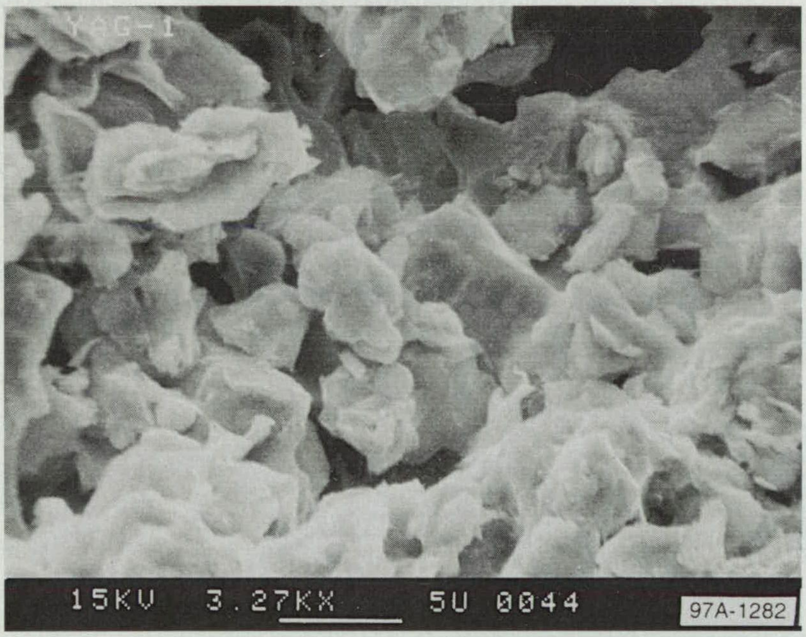


Figure 1. A **Scanning Electron Micrograph** shows a random porous single-crystal YAG.

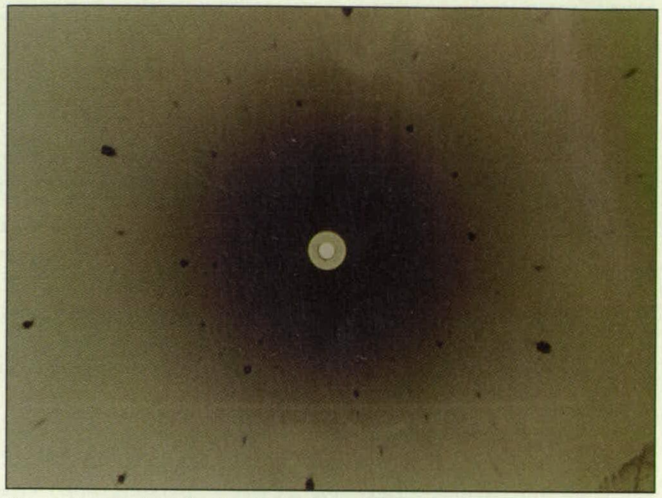


Figure 2. A **Back-Reflection Laue X-Ray Diffraction Pattern** from the preform in Figure 1 confirms its single-crystal nature.

forcing efficiency and infiltration with ceramic and intermetallic matrices.

Porous single crystals made by this proprietary approach also have applications such as selective emitters, filters, and photonic band-gap materials due to their unique physical properties. Porous single crystals of sapphire, YAG, eutectic YAG, doped sapphire, and ytterbia have been fabricated by this process and potential exists for fabricating porous single crystals of many other materials.

This work was done by Prashant G. Karandikar, Ronald Roy, and Uday Kashalikar of Foster-Miller, Inc., for **John H. Glenn Research Center.**

Inquiries concerning rights for the commercial use of this invention should be addressed to John H. Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16665.

Computing Chemical Kinetics With Low-Dimensional Manifolds

This method can be used to predict the concentration of NO_x in combustion exhaust.

John H. Glenn Research Center, Cleveland, Ohio

A method of computing the concentrations of chemical species in chemically reacting flows includes, among other things, utilization of a prior chemical-kinetic method based on a concept of intrinsic low-dimensional manifolds (ILDM) in composition space. The present method is particularly suitable for predicting concentrations of nitrogen oxides (NO_x)

Case Number	Predicted Concentration, Parts Per Million	Measured Concentration, Parts Per Million
1	20.5	21.6 to 26.5
2	6.9	10.6
3	4.9	12.0
4	13.9	3.1
5	28.5	35.1

Concentrations of NO_x as predicted by the present method approximated those measured in experiments in five test cases of combustion of hydrogen jets injected radially into a can downstream of an air inlet. The differences between predicted and experimental values for cases 2 through 5 should be analyzed with caution because the CFD computations for those cases were not carried out to full convergence.

generated in the combustion of hydrocarbon fuels in flows simulated by techniques of computational fluid dynamics (CFD).

The composition of a chemical system can be regarded as a point in composition space, which is a multidimensional space in which each dimension represents the concentration of one of the chemical species present. The chemical-kinetic rate equations of the system can be regarded as representing how the composition point moves in the space. In a typical case, the composition changes much more rapidly in some dimensions than in others, so that the composition point can be regarded as (1) first moving rapidly toward an attracting manifold of reduced dimensionality (for example, a surface in space of three or more dimensions), then (2) moving along the manifold toward an equilibrium point.

In the ILDM method, one identifies such a manifold, assumes that the composition always lies on the manifold, and uses the reduced dimensionality of the manifold to reduce the amount of computation needed to solve the corresponding equations of chemical kinetics. One still accounts for all of the chemical species of a complex system, but takes advantage of the simplification to parameterize the system by use of relatively few variables. In principle, the manifold can be identified once the number of its dimensions is known or assumed.

In the present method, the ILDM method is implemented by a computer code that automatically identifies a manifold on which a simplified mathematical model of a chemical system is parameterized by two variables: (1) a mixture fraction that is a function of mass fractions of species present in the system and (2) a progress variable, which can be either another function of species mass fractions, a temperature, or a Gibbs function. The only restriction on the choice of the progress variable is that this variable must be a single-valued function in the given system. The resulting species concentrations, rates, and properties are stored in look-up tables. These tables can then be used as the chemistry model in CFD calculations. By using look-up tables, the calculation of properties and reaction rates is replaced by interpolation, resulting in significant savings in central processing unit (CPU) time.

The method can also be used to post-process results of CFD simulations of reacting flows and, in particular, of flows in combustors burning hydrocarbon fuels in air. Typically, a CFD code yields the flow velocities, temperatures, and concentrations of the major chemical species (fuel, O_2, N_2, H_2O, CO, and CO_2). For each node on a computational grid, the mixture fraction and progress variable can be calculated from the CFD output data. Then with the help of interpolation routines that can be called from the CFD code, the mixture fraction and progress variable can be used to obtain concentrations of such minor species as NO_x (see table). This computation amounts to a mapping procedure that can be accomplished rapidly; computations for a million nodes take only a few minutes.

This work was done by A. T. Norris of the Institute for Computational Mechanics in Propulsion for **John H. Glenn Research Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to John H. Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16659.

Quadrupole Mass Analyzer Based on Linear Ion Trap

Size, mass, and power consumption would be reduced, relative to traditional QMAs.

NASA's Jet Propulsion Laboratory, Pasadena, California

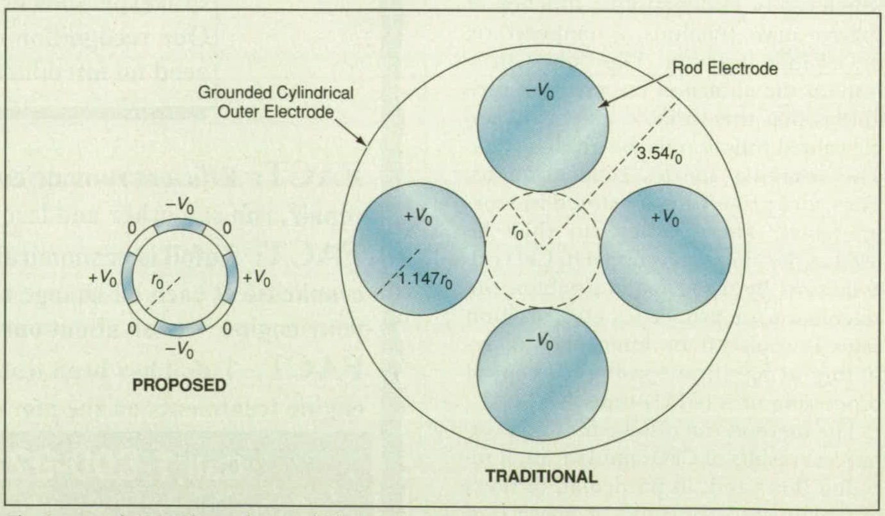
An improved quadrupole mass analyzer (QMA) has been proposed for use in determining the compositions of gas mixtures. The proposed QMA would incorporate two major innovations over traditional QMAs: (1) It would feature a simplified radio-frequency-excited quadrupole electrode structure that would be smaller, weigh less, and consume less power, relative to the quadrupole electrode structure of the corresponding traditional QMA; and (2) It would include dc end electrodes that would enable it to function as either a traditional transmission-mode mass spectrometer or an ion-trap mass spectrometer (ITMS).

The figure illustrates the proposed quadrupole electrode configuration and the corresponding traditional configuration, both designed for an inner radius r_0. In the traditional configuration, the outer cylindrical electrode is grounded, while a radio-frequency signal of amplitude V_0 is applied in opposite polarities to successive rod electrodes at 90° angular intervals. The radius of the quadrupole electrodes ($1.1468r_0$) and the radius of the outer shielding electrode ($3.54r_0$) are chosen to eliminate a sixth-order departure from the ideal quadrupolar electric potential and thereby obtain a close approximation to the ideal quadrupolar electric field.

The proposed quadrupole electrodes would be made from a single, precisely machined hollow cylinder cut lengthwise into eight sectors with alternating angular widths of 30° and 60°. The 30° sectors would be electrically grounded, while the radio-frequency signal of amplitude V_0 would be applied in opposite polarities to successive 60° sectors. This configuration would also eliminate the sixth-order departure from the ideal quadrupolar potential, yielding a similar close approximation to the ideal quadrupolar electric field. A simple comparison of overall radii shows that the cross-sectional area of the proposed QMA would be less than 1/10 that of the traditional QMA. If the proposed and traditional QMAs were of the same length, then the proposed QMA could be made to weigh about 1/10 as much.

Further analysis of the electric fields reveals that the proposed QMA could achieve the same stability parameters as does the traditional QMA at an excitation voltage about 10 percent smaller, and that the capacitance of the proposed QMA would be about 1/4 that of the traditional QMA. As a result, the energy stored in the electric field of the proposed QMA would be only about 1/5 that of the traditional QMA. As a further result, if the resonance quality factors of the excitation circuits were the same in both cases, the proposed QMA would consume only about 1/5 the power of the traditional QMA.

The ITMS version of the proposed QMA would be based on a linear ion trap, in which the trapping volume would be roughly a cylinder of length L and small characteristic radius R about the axis of symmetry. In contrast, a traditional ITMS is based on a point-node ion trap, in



The **Proposed QMA Electrodes** would feature reduced cross section and power consumption, relative to the corresponding traditional QMA electrodes.

which the trapping volume is roughly a sphere of radius R. Thus, the trapping volume of the proposed ITMS version would be about $3L/4R$ times that of a traditional ITMS. One could choose the dimensions of the electrodes to obtain $L >> R$, such that the trapping volume of the proposed ITMS version would be 100 to 1,000 times the volume of the corresponding traditional ITMS; the number of ions generated and trapped would be increased accordingly.

This work was done by John D. Prestage of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Technology Reporting Office
JPL
Mail Stop 122-116
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

Refer to NPO-20011, volume and number of this NASA Tech Briefs *issue, and the page number.*

Inflatable Membrane Reflectors for Multiple-Purpose Applications

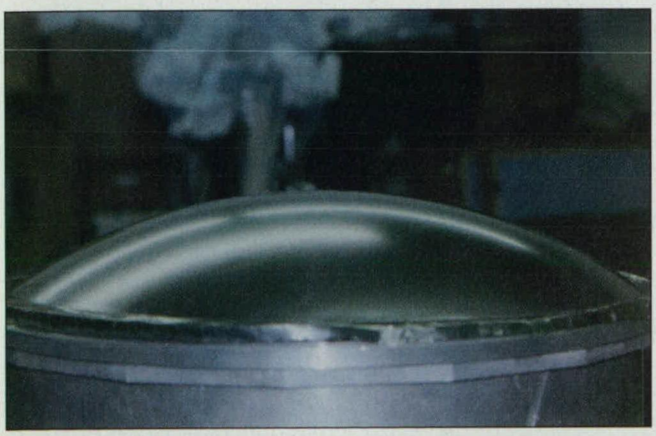
Attention to details of design and modeling could result in fairly precise surfaces.

NASA's Jet Propulsion Laboratory, Pasadena, California

Experiments have demonstrated the feasibility of inflatable reflectors with very low system aerial densities of the order of 1 kg/m^2. Diverse applications include radio and optical communications, telescopes, and the concentration of sunlight for power generation. The same technology can be used for structural beams in single or multiple layers with excellent rigidity. Development work thus far has focused on potential uses in outer space, but inflatable rigidized structural elements are suitable for terrestrial applications where large lightweight surfaces and structures are needed.

The basic concept of an inflatable reflector is simple: stretch a membrane beyond its elastic limit by using a combined mechanical tensioning and pressure. The shape the resulting surface takes is a good approximation to an ellipse with higher order correction terms. The shape can be modified by changing the boundary, the pressure, or the membrane material. A change in area of approximately 1 percent is required to plastically deform the membrane into the desired shape. After forming, the pressure is released with the resulting surface being a self-supporting membrane reflector. For imaging applications, the aberrations induced by the membrane reflector could be compensated for by secondary and tertiary optics. The design problem is to choose the membrane material and boundary conditions to obtain the desired reflector shape.

The figure shows an experimental apparatus on which a stainless steel membrane is stretched across a circular boundary and pressurized. The result is a smooth, rigid, self-supporting curved reflector surface of a quality suitable for use as a mirror in the far-infrared or submillimeter wavelengths (measured surface 8 micrometers root-mean square [RMS] over the central 40 cm of the membrane). The global surface figure can be adjusted by changing the pressure, the stretching forces, or the boundary over which the membrane is stretched.



A Stainless Steel Membrane is stretched across a circular boundary and pressurized to deform it into a curved mirror.

This work was done by Neville Marzwell of Caltech and Mark Dragovan of the Fermi Institute, University of Chicago, for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
NPO-20359

Books & Reports

Active Homopolar Magnetic Bearing

A report presents information on an earlier work on active magnetic bearings with high-critical-temperature superconducting coils. To recapitulate, the device is a homopolar radial-type active magnetic bearing with a bias coil and control coils made of a high-critical-temperature superconductor. The report discusses major features of the design and operation of the bias and control coils, measurements of ac power losses in the control coils, and results of experiments in which the device was operated at the temperature of liquid nitrogen. The experimental findings and conclusions stated in the report are nearly identical to those noted earlier. One particularly notable conclusion is that ac losses appeared to be related to coil inductances and that it may therefore be possible to reduce these losses by winding the control coils from twisted, multifilamentary forms of the superconductor.

This work was done by G. V. Brown, E. DiRusso, and A. J. Provenza of **John H. Glenn Research Center.** *To obtain a copy of the report, "An Active Homopolar Magnetic Bearing With High Temperature Superconductor Coils and Ferromagnetic Cores," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to John H. Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16419.

Properties of Cubic Boron Nitride Films

A report describes an experimental study of the surface-chemical, microstructural, and tribological properties of cubic boron nitride (c-BN) films, which are potentially useful as hard, wear-resistant coatings on bearings and on steel-cutting tools. For the experiments, BN films about 500 nm thick were synthesized by magnetically enhanced plasma ion plating onto titanium interlayers on mirror-finish silicon substrates. The films were characterized by x-ray photoelectron spectroscopy, transmission electron microscopy, electron diffraction, Fourier-transform infrared spectroscopy, atomic-force microscopy, and surface profilometry.

This work was done by Donald R. Wheeler, Phillip B. Abel, Kenneth W. Street, and Kazuhisa Miyoshi of **John H. Glenn Research Center** *and Shuichi Watanabe, Masao Murakawa, and Shojiro Miyake of the Nippon Institute of Technology. To obtain a copy of the report, "Surface Chemistry, Microstructure, and Tribological Properties of Cubic Boron Nitride Films," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to John H. Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16695.

Crimping Thin PTFE Tubes Onto Thin Stainless-Steel Tubes

Crimps prove superior to wrapped wires, flared tubes, ringed hose barbs, and the like.

John H. Glenn Research Center, Cleveland, Ohio

A crimping technique has been developed for fastening polytetrafluoroethylene (PTFE) tubes of 0.032-in. (0.81-mm) outside diameter and 0.0105-in. (0.267-mm) inside diameter onto stainless-steel hypodermic tubes of 0.0105-in. (0.267-mm) outside diameter. The technique was developed to provide lightweight connections that would not slip or leak when subjected to rapid, repeated movements.

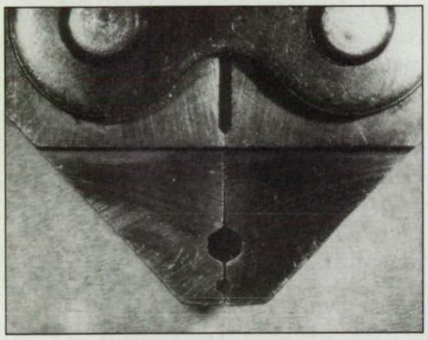


Figure 1. The **Crimping Tool** is a modified pair of crimping pliers containing a hexagonal crimping die. The hexagon was chosen over other shapes because it minimizes the amount of copper extruded from the sleeve during the crimping process.

The technique is needed because connections made with such conventional means as wrapped and/or twisted wires, flared tubes, ringed hose barbs, and combinations of these eventually slip and/or leak when handled or moved repeatedly.

The development of the technique included tests that revealed that the best crimp reduction for PTFE is about 18 percent. The dimensions of the crimping sleeves and the crimping tool were chosen accordingly. The crimping sleeves were made from copper rods of 0.047-in. (1.2-mm) diameter, cut to 1/8-in. (3-mm) length, and drilled to an inside diameter of 0.033 in. (0.84 mm). The crimping tool was made by machining a pair of crimping pliers down to a thickness of about 0.100 in. (2.54 mm) and cutting a 0.038-mm (0.97-mm) hexagonal crimping die into its tip (see Figure 1).

Optionally, one can prepare the crimp area on the stainless-steel tube with a light grit blast prior to joining to improve the subsequent grip on the tube. To make a connection, one first slips the copper crimping sleeve over the PTFE tube, then inserts the stainless-steel tube into the PTFE tube a sufficient distance to enable proper positioning of the crimping sleeve as described next. The crimping sleeve is positioned so that PTFE and stainless-steel tube segments 0.05 to 0.06 in. (1.3 to 1.5 mm) long protrude from opposite ends of the crimping sleeve. The tool is then applied to effect the crimp. Figure 2 shows a completed connection.

Limited experience thus far seems to indicate that a connection made by this technique does not leak measurably when exposed to vacuum or to pressure up to 115 psi (0.79 MPa). The technique can readily be modified, by appropriate changes in dimensions of the sleeves and tool, for PTFE and stainless-steel tubes of different diameters. Potential uses for this technique could include

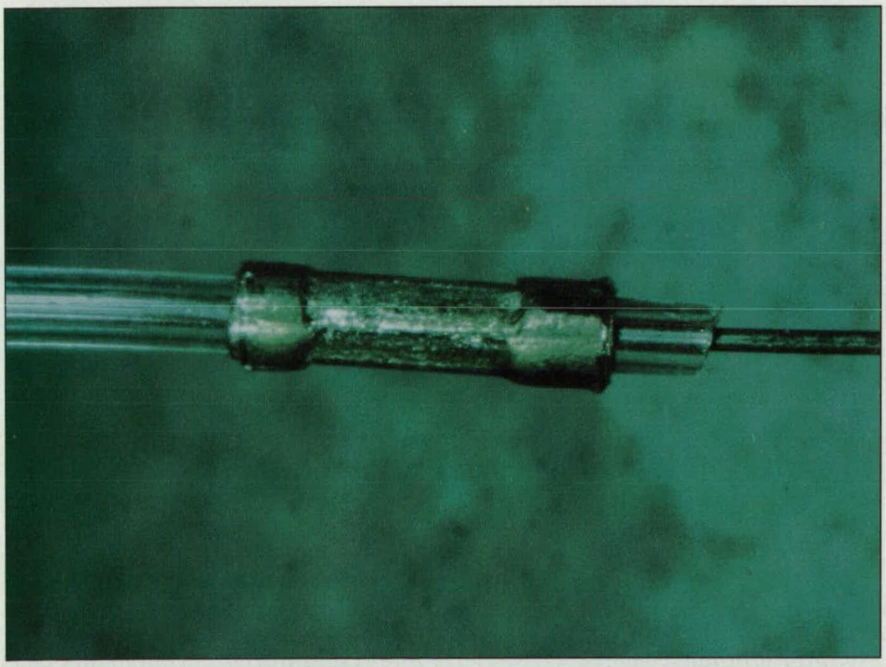


Figure 2. A **Crimped Connection** made by the present technique grips more strongly than does a connection made by the traditional twisted-wire technique. One reason for the superiority of the present technique is that the grip is spread over a larger area.

joining fuel lines for gas-powered models, joining pneumatic and gas lines in general, and perhaps joining tubes in medical equipment.

This work was done by Myron M. Joseph (retired) and George J. Saad of **John H. Glenn Research Center**. *For further information, access the Technical Support Package (TSP) free on-line at www.nasatech.com under the Manufacturing/Fabrication category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to John H. Glenn Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7–3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16689.

Polymeric Composite Damage Protective Overwraps for Composite Pressure Vessels

These overwraps would weigh less than conventional glass-fiber-based damage protective overwraps do.

NASA's Jet Propulsion Laboratory, Pasadena, California

Damage-tolerant polymeric composite overwraps have been proposed for lightweight pressure vessels that are made of composites of graphite fibers in polymeric matrices. Graphite-fiber/polymer composites are vulnerable to impact damage; overwraps on the pressure vessels help to protect against such damage.

In current practice, an overwrap is made of a composite of glass fibers in a polymeric matrix. The glass fibers are too weak to contribute significantly to the structural strength of the underlying pressure vessel, and the glass-fiber-based overwrap adds significantly to the weight of the vessel.

According to the proposal, the outer layers of a graphite-fiber/polymer pressure vessel would be made of polybenzoxazole (PBO) fibers in a polymeric matrix. The PBO fibers would protect the underlying graphite/polymer composite layers against impact damage, but unlike glass fibers, the PBO fibers would be almost as structurally efficient as the graphite fibers. Layers of PBO fibers could even be used as substitutes for some of the layers of graphite fibers, in which case the overwrap would contribute very little additional weight to the vessel.

This work was done by Joseph Lewis of Caltech for **NASA's Jet Propulsion Laboratory.** *No further documentation is available. NPO-20442*

Hybrid Composite Overwraps for Low-Pressure Tanks

The weight contributed by the overwraps on the end surfaces would be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

Hybrid versions of the high-performance overwraps used on some low-pressure tanks have been proposed. The hybrid overwraps would weigh less than do the corresponding nonhybrid overwraps, as explained below.

In current practice, the overwrap material used on all areas of a tank is a composite that contains graphite fibers. The minimum tape thickness of this overwrap material is about 0.005 to 0.007 in. (≈0.13 to 0.18 mm); consequently, the thickness of the low-angle-helical (L.A.H.) wrap on each end surface of the tank cannot be made less than about 0.010 to 0.014 in. (≈0.25 to 0.36 mm). However, thinner L.A.H.-wrap thicknesses are needed on the ends of most tanks of this type; in such cases, the excess thicknesses of carbon-fiber-based overwraps give rise to unnecessary weight penalties.

According to the proposal, the material for the L.A.H. end wraps would be a composite based on polybenzoxazole (PBO) fibers. The minimum tape thickness of the PBO-fiber-based overwrap material would be about 0.001

in. (≈0.025 mm), and the strength and elastic modulus of PBO fibers is almost equal to that of graphite fibers; as a result, no weight penalty would exist for an end wrap based on PBO fibers.

Also according to the proposal, the hoop wrap on the cylindrical portion of a tank would still be made of the conventional graphite-fiber-based composite material. This would not entail an unnecessary weight penalty because the needed hoop-wrap thickness is greater than the minimum graphite-fiber tape thickness.

This work was done by Joseph C. Lewis of Caltech for **NASA's Jet Propulsion Laboratory.** *No further documentation is available.*
NPO-20443

Integrally Wound Skirt for Composite-Overwrapped Tank

Strength would be increased and weight reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

The skirt that supports a composite-overwrapped tank would be made an integral part of the composite overwrap, according to a proposal. In current practice, the structure that supports a composite-overwrap tank usually includes a layer of rubber between the tank and its skirt. The rubber layer is heavy and constitutes a relatively weak link in the tank-supporting structure.

The proposal arose from an investigation of how to reduce the weight of the tank and its supporting structure, considering the tank as part of an overall tank/structure system. The investigation revealed that elimination of the rubber layer could reduce the weight of the system considerably.

The fiber reinforcement in the skirt would be filament wound directly onto the tank, without an intervening layer of rubber. The weight of the tank/structure system would be reduced and the strength of the skirt/tank bond increased accordingly, and the skirt would bear part of the hoop stress of the tank.

This work was done by Joseph C. Lewis of Caltech for **NASA's Jet Propulsion Laboratory.** *No further documentation is available.*
NPO-20455

Repair of Composite-Overwrapped Pressure Vessels

It would no longer be necessary to replace entire expensive vessels in cases of localized damage.

NASA's Jet Propulsion Laboratory, Pasadena, California

Pressure vessels overwrapped with graphite-fiber-based composite materials that become damaged would be salvaged by a proposed repair technique. The need for the technique arises as follows: High-performance graphite-fiber-based composites are very susceptible to damage from impact or cutting. Heretofore, when a composite-overwrapped vessel has been damaged, it has been necessary to replace the vessel in its entirety. However, some vessels of this type are so large and expensive that it is uneconomical to discard them in the event of damage.

The proposed repair technique would involve adhesive bonding of a composite doubler over each damaged area. The doubler would transfer structural loads around the damaged area.

The fiber reinforcement in a doubler could be made of graphite, polybenzoxazole, or aromatic polyamid, for example. The fiber and matrix materials and the dimensions of the doubler would be chosen by design to suit the specific damaged area. The doubler would be bonded in place by use of a room-temperature-curing adhesive. Use of additional fiber overwrapping of the doubler would be determined on a case-by-case basis.

This work was done by Joseph C. Lewis of Caltech for **NASA's Jet Propulsion Laboratory**. *No further documentation is available.*
NPO-20456

Ceramic Composites of ZrB_2, HfB_2, ZrC, HfC, and SiC

These ceramics offer superior resistance to ablation at high temperature.

Ames Research Center, Moffett Field, California

Improved zirconium- and hafnium-based ceramic composites have been invented in an effort to obtain better resistance to ablation at high temperature. These ceramics are suitable for use as thermal-protection materials on the exterior surfaces of spacecraft reentering the terrestrial atmosphere, and in laboratory and industrial environments that include flows of hot oxidizing gases.

The predecessors of these ceramic composites are ZrB_2/SiC and HfB_2/SiC composites, which exhibit high resistance to oxidation and thermal shock, high configurational stability, and high resistance to ablation. The ablation resistance of ZrB_2/SiC and HfB_2/SiC composites is believed to arise from the formation of coherent passivating oxide scales on their surfaces. However, each such composite exhibits a transition point

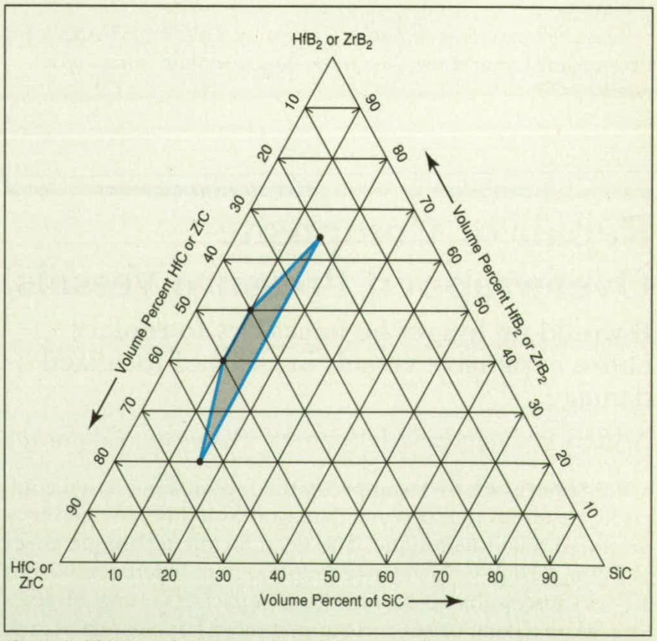


Figure 1. This **Pseudo-Ternary Phase Diagram** is for a ceramic composite of either (1) ZrB_2, ZrC, and SiC or (2) HfB_2, HfC, and SiC. The preferred composition ranges mentioned in the text are represented by the shaded trapezoidal area.

Composition in Volume Percentages		Effective Conversion Rate, µm/min.	Peak Surface Temperature, °C
64 ZrB_2 + 20 ZrC + 16 SiC	Newer Compositions	–0.98	2,020
64 ZrC + 20 ZrB_2 + 16 SiC		–6.83	2,100
80 ZrB_2 + 20 SiC	Older Compositions	–17.78	2,200
80 HfB_2 + 20 SiC		3.47	1,810

Figure 2. **Effective Conversion Rates** and peak surface temperatures are indicators of resistance to ablation. A negative effective conversion rate represents growth or effusion of oxide scale on the surface of the ceramic, while a positive effective conversion rate signifies removal and conversion of surface material.

within its operational envelope of mach number vs. stagnation heat flux; beyond this point, the cohesiveness of the oxide scale decreases in such a way that microspallation of the oxide scale and concomitant accelerated conversion occur. Thus, resistance to ablation decreases beyond the transition point. The present innovative ceramic composites offer superior resistance to ablation.

A ceramic of the present type is a multiphase composite of (1) zirconium diboride and zirconium carbide with silicon carbide, (2) hafnium diboride and hafnium carbide with silicon carbide, or (3) mixed diborides and/or carbides of zirconium and hafnium with silicon carbide. The composite material is made by sintering a mixture of the metal diboride, metal carbide, and silicon carbide powders at a temperature of about 1,900 °C or greater. Typical composition ranges in volume percentages of the starting ceramic powders are the following:

Constituent	Proportion, Volume Percent
ZrB_2 and/or HfB_2	20 to 64
ZrC and/or HfC	20 to 64
SiC	≤20 (Preferably 10 to 16)

A given composition is said to be diboride- or carbide-rich, depending on the ratio between the metal diboride and metal carbide contents.

Figure 1 is a pseudo-ternary phase diagram for the special case of composites made from either (1) ZrB_2, ZrC, and SiC or (2) HfB_2, HfC, and SiC but not (3) mixtures of the diborides and/or carbides of both Zr and Hf. "Pseudo-ternary phase diagram" as used here signifies that the three points of the triangle represent the starting ZrB_2 or HfB_2, ZrC or HfC, and SiC components, as distinguished from a true ternary diagram in which the individual elements Zr or Hf, Si, and C are represented. The composition ranges stated above are represented by the shaded trapezoidal area.

The table in Figure 2 presents some results of a test in which two composites of the present type and two of the previous type were exposed to an arc jet at a heat flux of 400 W/cm^2. The results show that with respect to conversion rates, the present ceramic composites resist ablation or conversion better than do the corresponding predecessor ZrB_2/SiC and HfB_2/SiC composites. The results are even more impressive when densities and surface temperatures are taken into account: About 50 seconds into the test, the ZrB_2/SiC ceramic underwent a transition in which the surface temperature rapidly climbed to a maximum of 2,200 °C, with resultant micro and macro spallation, and stability was not reestablished.

This work was done by Jeffrey Bull of **Ames Research Center**, *Michael White of White Materials Engineering, and Larry Kaufman of Cambridge Technology Center. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

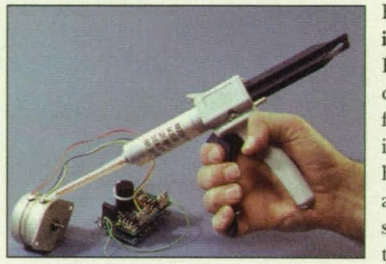
This invention has been patented by NASA (U.S. Patent No. 5,750,450). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center; (650) 604-5104. Refer to ARC-12087.

Special Coverage: Composites & Plastics

DuPont, Wilmington, DE, offers Krytox® **dry film** that can reduce the coefficient of friction in a range of applications, including mold release, allowing rubber and plastic parts to eject faster and cleaner. It also creates non-stick surfaces and facilitates parts movement. For the internals of switches, a coating of the film permits movement without attracting dirt.

The Krytox dry film also can be used in wire drawing applications, in which it coats wire as it is pulled through a die, reducing heat generation and increasing the speed of the pull. The film joins the Krytox family of products, which includes oils and greases, and high-performance lubricants such as XP PFPE lubricants.

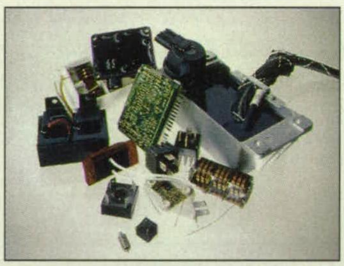
For More Information Circle No. 759



EP21AR **polymer adhesive** from Master Bond, Hackensack, NJ, is a two-component epoxy adhesive for high-performance bonding in applications where high chemical resistance is a requirement. The adhesive cures at room temperature, or more rapidly at elevated temperatures. It has a two-to-one mix ratio by weight, and develops a bonding strength of more than 2000 psi at room temperature.

The adhesive produces bonds that are resistant to thermal cycling and chemicals, including strong acids, alkalis, water, salts, and many organic solvents, over a temperature range of -60 °F to more than +250 °F. It withstands prolonged immersion in concentrated sulfuric acid, as well as high concentrations of nitric and hydrochloric acid. The adhesive adheres to metal, glass, ceramic, wood, vulcanized rubber, and plastic; the hardened adhesive is an electrical insulator.

For More Information Circle No. 705



Loctite® Encap® two-part epoxy and polyurethane **potting and encapsulating compounds** from Loctite Corp., Rocky Hill, CT, protect critical components from the effects of exposure to chemicals, moisture, thermal and mechanical shock, and vibration. They also prevent corrosion and ensure integrity of electrical and electronic devices. The line features five two-part epoxy systems for temperatures in excess of 125 °C. The two-part systems involve and epoxy or polyurethane resin and an associated hardener, which initiates cure.

Also available are three two-part polyurethane resins, which operate most effectively in temperatures below 250 °F. When combined with the appropriate polyurethane hardener, the resins offer adhesion and abrasion resistance, high impact strength, and flexibility at low temperatures. These systems are suited for applications involving delicate components that will be exposed to sub-zero temperatures.

For More Information Circle No. 704

Bixby International, Newburyport, MA, has introduced **multilayer composites** that are extruded and laminated in one step. The process produces rigid or flexible plastic sheet and film, coated fabric, and plastic, foam, and fabric composites for uniformity and durability. The process combines up to five layers (two fabrics and three plastics) in one pass.

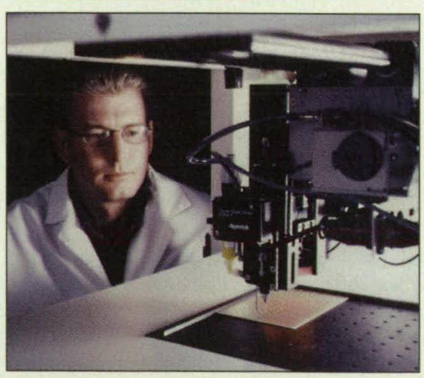
Custom composites are available in a variety of polymers, foams, papers, and fabrics. Various adhesive and plastisol coatings, custom color matching, and full-color sublimation printing also are available. Extruded and laminated products can be produced in thicknesses ranging from 6 to 250 mils (1/4").

For More Information Circle No. 703

Polydamp® Low Emissivity Foam (PLE) from Polymer Technologies, Newark, DE, is a **thermal foam material** for insulating equipment where operators or components need to be kept at very stable temperatures. It is designed for trucks, medical diagnostic equipment, refrigeration applications, and buildings.

The construction of the material addresses three thermal problems: conduction, convection, and radiation. It is available in sheets, rolls, or fabricated shapes, and is available with an optional PSA backing. The foam is part of the company's line of acoustical composites and engineered foam products for acoustical, gasketing, shielding, and structural applications.

For More Information Circle No. 700



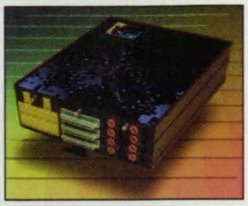
Emerson & Cuming Specialty Polymers, Billerica, MA, offers ECCOBOND® CS 6000 electrically conductive **adhesive**,which reduces stress in the bonding of electrical or electronic components. The silver-filled silicone material has favorable electrical and thermal conductivity properties and a low tonic impurity, making it suitable for die and component attachment.

The adhesive features flexibility and has tough adhesion over wide temperature cycles. The single-component, silver-colored paste cures in one hour at 150 °C, and has a work life of eight hours.

For More Information Circle No. 701

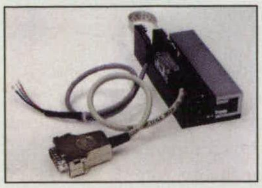
New on the MARKET

Portable Data Acquisition



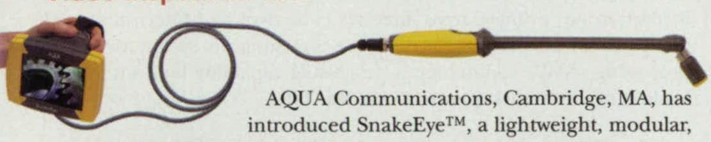
IOtech, Cleveland, OH, has introduced the Daqbook/260™ portable data acquisition system for notebook and desktop PCs. The system combines measurement and control I/O with user-configurable signal conditioning and signal connection. Three internal expansion slots accommodate any combination of signal conditioning and expansion options, including thermocouple, RTD, strain, high-voltage, current, frequency, acceleration, and pressure. The system features 16-bit resolution, 100-kHz sampling, and up to 64 channels of analog input using optional expansion cards. The unit is attached to the parallel port or PCMCIA slot on a PC. It comes with IOtech's DaqView™ Out-of-the-Box™ data acquisition and display software. **Circle No. 720**

Linear Positioner



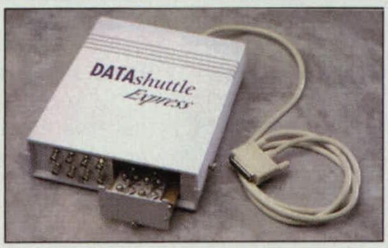
Baldor Electric, Northern Magnetics Div., Fort Smith, AR, has released a Compact Positioning Stage, which features a zero-backlash, non-wearing linear motor that eliminates mechanical-drive linkages to provide smooth, quiet operation. The stage has a maximum stroke of 2" (0.5 Min) and an approximate total weight of 1.5 pounds. It offers continuous forces to 1 pound, and peak forces to 3 pounds. Designed originally for laser eye-surgery applications, the positioner is suitable for semiconductor manufacturing, medical equipment, precision machining, and inspection and measurement equipment. **Circle No. 719**

Video Inspection Tool



AQUA Communications, Cambridge, MA, has introduced SnakeEye™, a lightweight, modular, portable video diagnostic tool that combines a miniature CCD camera with TFT-LCD display technology. The unit delivers full-color video and features a video in/out port, which allows connection to a standard VCR or to a PC video capture card. SnakeEye is designed for qualitative inspections in hard-to-reach places such as engines and fuel tanks. The device comes with a rechargeable battery pack, AC adapter, and an auto adapter. Options include a 3-foot gooseneck adapter and C-mount camera. **Circle No. 731**

Data Acquisition



OMEGA Engineering, Stamford, CT, offers the Datashuttle Express (DS-EXP), a high-speed portable data acquisition system. Features include high-speed sampling rates of up to 100 kHz and 0.012% A/D resolution. The system accepts several input types, including thermocouple, accelerometer, RTD, and strain gauge, along with digital I/O, analog output, and counter/timer. Multiple units can be interfaced to a single PC for 240 analog inputs, 30 analog outputs, 30 counter/timers, and 180 digital I/Os. It comes with Quicklog software, which enables low-speed data acquisition, datalogging, charting, and DDE capability. **Circle No. 713**

New on DISK

Link for Excel

Wolfram Research, Champaign, IL, offers Mathematica Link for Excel, which provides an interface between Microsoft Excel and the Mathematica technical-computing system. The software allows Excel spreadsheets to perform integration and differentiation, and solve differential equations. It enables users to perform data analysis using Mathematica's statistics capabilities, including data smoothing and manipulation, linear and nonlinear regression with diagnostics, and hypothesis testing. With the linking software, Mathematica Applications Library add-ons such as Finance Essentials also can be brought into Excel. **Circle No. 732**

Vision Application Builder

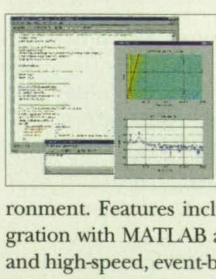
IMAQ Vision Builder from National Instruments, Austin, TX, is an interactive software environment for the development of computer-based vision systems. Its set of machine-vision and image-processing tools includes functions for quantitative analysis, image enhancement, grayscale, color, morphology, blob analysis, and pattern matching. The software also returns critical tolerance measurements such as distances, areas, and locations, and enables developers to load images from files or capture images from analog or digital cameras. The software is optimized for speed with Intel's MMX processors and includes an image browser. **Circle No. 734**

Numerical Library

Visual Numerics, Boulder, CO, has introduced Version 3.0 of IMSL C Numerical Library (CNL), which consists of more than 250 pre-built mathematical and statistical analysis functions written in C. Programmers of C or C++ can embed the functions directly into numerical analysis applications. Version 3.0 offers 22 new statistical functions focused in two primary areas: time series analysis and forecasting, and non-parametric statistics. The software also supports symmetric multiprocessing (SMP) technology, a processing capability built into many leading PCs and workstations. **Circle No. 739**

CAD Model Repair

CADfix™ from International TechneGroup, Milford, OH, is designed to facilitate product data interoperability. It assesses geometric and topological imperfections in CAD models (IGES, STL, Parasolid, ACIS) and makes the corrections automatically or interactively. CADfix features "smart healing" technology, intuitive model partitioning tools for CAE applications, and comprehensive NURBS surface-repair functions. The software allows a repaired model to be transformed so that data is suitable for the end-user application. **Circle No. 737**



Data Acquisition Tool

The MathWorks, Natick, MA, has released the Data Acquisition Toolbox, designed to provide direct access to live, measured data from MATLAB computation and visualization software. Users can acquire, analyze, visualize, model, and report data results in one environment. Features include analog input/output and digital I/O; integration with MATLAB and MATLAB toolboxes; multi-channel support; and high-speed, event-based acquisition. The Toolbox supports National Instruments' E-Series boards, HP's VXI E1432-Series hardware, Microsoft Windows' multimedia sound card, and third-party extensions by vendors such as DSP Technologies. The toolbox is Windows 95/98/NT compatible and requires MATLAB 5.3. **Circle No. 735**

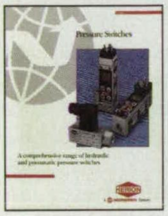
New LITERATURE

Fasteners and Inserts

Penn Engineering & Manufacturing Corp., Danboro, PA, offers a Product Guide and Index to Bulletins detailing fasteners, inserts, and fastener-installation press systems. This 12-page guide also provides an index to product literature and contact information for authorized distributors and engineering representatives worldwide. **Circle No. 722**

Optoelectronics CD-ROM

Sharp Microelectronics of the Americas, Camas, WA, has released a CD-ROM describing optoelectronic devices, applications, power devices, GaAs Hall devices, and Hall ICs. The CD contains more than 1,500 pages of data on products including photocouplers, photointerrupters, visible LEDs, laser diodes, and solid state relays. **Circle No. 724**



Pressure Switches

Pressure switches catalog #N-404 from Norgren-Herion USA, Warrendale, PA, offers a range of switches for pneumatic, hydraulic, and process-control applications. The 32-page catalog includes both electromechanical and digital solid-state models, for pressures from vacuum to 10,000 psi. **Circle No. 725**

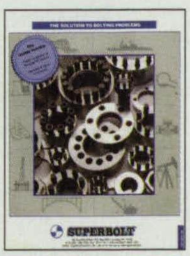
Field Calibrators

A 12-page catalog from Fluke Corp., Everett, WA, describes the Fluke 740 line of documenting process calibrators. Products include the Fluke 744, which is designed for calibrating, maintaining, and trouble-shooting HART instrumentation. Other new products include the Fluke 718 Pressure Calibrator and the Fluke 705 Loop Calibrator. **Circle No. 727**

Linear Guides

Thomson Industries, Port Washington, NY, offers a 186-page catalog featuring 17 types of RoundRail™ and ProfileRail™ linear guides. Included are linear guides with different contact technologies (ball, roller, sliding bearings); mounting types (fully supported, unsupported, end supported); and mounting styles (above, below, side). **Circle No. 728**

Bolting Solutions



A revised catalog from SUPERBOLT, Carnegie, PA, contains technical information on mechanical and stud/bolt tensioners, and an updated installation/removal procedure. Products include reusable Multi-Jackbolt tensioners, which are designed so that bolts can be tensioned using only a hand torque wrench. **Circle No. 723**

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